NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4212

CENTRAL AUTOMATIC DATA PROCESSING SYSTEM

By the Staff of the Lewis Laboratory

Lewis Flight Propulsion Laboratory
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4212

CENTRAL AUTOMATIC DATA PROCESSING SYSTEM

CHAPTER I

GENERAL DESCRIPTION

By Bert A. Coss

SUMMARY

This series of papers describes a system that will automatically record as many as 300 pressures, 200 voltages, and 24 frequencies in as little as 30 seconds to an accuracy of 0.15 percent or better of full-scale range. All information is digitized, encoded, and recorded on magnetic tape for automatic insertion into a high-speed, general-purpose digital computer. Provisions for recording computer program modification instructions are incorporated. The recorder may be connected to any of eight different test facilities, any four of which may be operating simultaneously. The system is in daily operation on a 24-hour basis and has an operating history of more than 2 years.

The computer accepts the encoded data produced by the recording system and automatically calibrates it, takes averages, forms ratios, and does terminal calculations such as mass flow, momentum, distortion numbers, drag coefficients, thrust, specific fuel consumption, and efficiency. This computer has been in operation for approximately 1 year and enables the computed data to be returned to the test engineer the next day.

INTRODUCTION

The processing of the volume of data produced daily at the NACA Lewis laboratory presents an almost insurmountable task if handled by normal manual processing methods. Several years ago, automatizing the processing of pressures (ref. 1) relieved this situation somewhat. The success of that instrument led to expansion of the system and centralization of the equipment. The status of this system is presented in this report.

The philosophy followed was that a central data recording device would be connected by means of telephone-type cable to remote transducing equipment. The central recording equipment would contain most of the electronic equipment. It would be manned by experienced operating and maintenance personnel at all times, even though the operation is essentially automatic. The remote transducing equipment would be inexpensive and simple with an absolute minimum of electronics and would be completely automatic and unattended. After recording, the data would be processed on a stored-program, high-speed, general-purpose digital computer. The computed data, including all terminal calculations called for by the project engineer at the facility, would be available to him the next day. 4256

RECORDING SYSTEM

Figure 1 is a block diagram of the complete system. Only the general features of the system will be discussed here as more specific details of the individual component parts are discussed in the other chapters.

The test section, the transducers, and the control room are remotely located but when taken together are called the remote test facility (fig. 1). There are eight of these remote test facilities which can be connected to the Central Automatic Digital Data Encoder (CADDE). However, only four may be connected at any given time, since only four tape handlers are available.

The remote test facility is connected to the CADDE area of the central data processing room by means of a telephone-type cable as discussed in chapter II.

As many as 200 voltages from equipment such as thermocouples, strain gages, potentiometers, and manual switches can be measured and converted to digital form, one at a time, by an Automatic Voltage Digitizer (AVD) as outlined in chapter III.

Up to 24 pieces of any information which can be represented by a frequency in cycles per second or other events per unit time (herein called E.P.U.T.) can be taken through the E.P.U.T. transducer and accumulated in the temporary storage. This system is discussed more fully in chapter IV.

Up to 300 pressures can be taken from the model under test through copper tubing to the Digital Automatic Multiple Pressure Recorder (DAMPR) system and are transformed into electrical signals which store numbers in temporary storage as detailed in chapter V.

In order to start a recording cycle it is only necessary for the test engineer in the facility control room to push a button. All necessary connections are automatically made and checked, all necessary commands are automatically given and carried out, and the equipment is returned to "ready" condition in preparation for the next cycle. Signal lights in the control room keep the engineer informed of equipment status throughout the cycle.

Pushing the "call" button, assuming that CADDE is in condition to record, starts the pressure scan of the DAMPR system and starts the E.P.U.T. and the AVD systems. The outputs of these systems are fed into the temporary storage and sequence control block and are either held temporarily to arrange them in proper order or are passed through immediately as required. Identification, word numbering, and editing and control instructions are added automatically, and the data are fed out in a prescribed sequence according to a predetermined program. The output is then fed into the recording bus and is recorded on one of the tape handlers A, B, C, and D. In addition, certain preselected words are recorded simultaneously on tape handler X. The recording rate is 20 words per second for all data except AVD, which may be at different rates depending on the individual digitizer used.

The recording cycle is now complete. The message or reading which is now stored on magnetic tape contains, in a predetermined format, all the information, including identification, that is necessary for computing values called for by the project engineer at the facility. A more detailed discussion of the equipment and the procedures used in the recording system is given in chapter II.

PLAYBACK SYSTEM

To ensure that the CADDE system is working properly, it is necessary for the CADDE operators to check all readings that are recorded. Both automatic and manual means have been provided to do this. This information can also be sent back to the control room, so that slide-rule calculations can be made during the course of the test for control purposes.

As shown in figure 1, the output bus from tape handlers A, B, C, and D has three branches. Any tape handler may be connected to any branch, but no two may be connected at the same time to the same branch. However, different tape handlers may be connected to different branches at the same time. Thus, it is possible to have all four tape handlers running at the same time, with each doing a different operation.

The branch leading to Flexowriter A is the circuit normally used for routine typing. It must be used if recording on other tape handlers is to be done during the typing operation. Either "full type" or "select type" operations may be performed at the operator's option. "Full type" means that every word in the reading is typed out. "Select type" means that only preselected words which have had a particular symbol recorded in the word will be typed out. Since an alternate, completely automatic, "select type" operation is available, as will be seen later, the normal use of this branch is for "full type" operations. The information can be typed back to the remote facility simultaneously.

The branch leading to the facsimile plotter permits examination of the raw data in a form similar to a calibrated bar graph. The value of this equipment lies in the easy comparison of proportional numerical values much like a manometer board and in the fact that data can be recorded so rapidly. This equipment plots 15 data words per second as compared with one word per second for typewritten copy. All readings taken are plotted on this device. This plot can be made either at CADDE or at the remote facility, but not at both simultaneously. The plotter itself is commercially available from the Alden Products Company, but the electronics to drive it were developed at the NACA and are discussed in chapter VI in connection with the complete playback system.

The branch leading to the computer permits the feeding of information from any tape handler into the computer for calibration and terminal calculation. This operation is discussed more fully later in this chapter.

Tape handler X and Flexowriter B comprise a special playback circuit that can be designated as an automatic monitoring system. It has been mentioned previously that certain preselected data words could be recorded on X at the same time as on the other tape handlers. In practice, the "select type" data words from all readings are recorded on X. There is then a chronological log of all readings recorded on X. Tape handler X differs from the other magnetic-tape handlers in that it uses an endless loop of tape and has separate recording and playback stations. Since it is completely automatic in operation, it requires no operator's attention except to keep the Flexowriter supplied with paper. It was designed and built by the NACA and is described in chapter VI.

In addition to these automatic checks, it is possible for the CADDE operator to intervene manually on any tape handler. Detailed word-by-word examination of what is recorded on the tape by means of indicator lights or typed words allows him to determine the cause of malfunctions indicated by the automatic devices and to take corrective action, if necessary.

If it seems that undue emphasis has been placed on playback devices, it must be pointed out that each was developed to satisfy a demonstrated need as determined from operating experience. The ability to tell the computer operating group in advance where and when a bad piece of data would be found has saved untold hours of computer operating time.

COMPUTER SYSTEM

The destination of the information recorded at CADDE is a high-speed, general-purpose, stored-program digital computer. Specifically, it is a Sperry-Rand type 1103 Scientific Univac. In the computer the raw data from CADDE have calibration constants applied to convert to true physical quantities, averages are taken, and ratios are formed as the data are read in and stored. After storing, terminal calculations are performed by using the stored data as required. Such items as mass flow, momentum, distortion numbers, drag coefficients, thrust, specific fuel consumption, and efficiency can be obtained as directed by a previously determined stored program.

The programs are read into the computer by means of the Ferranti paper-tape reader and are stored (fig. 1). As many as ten programs can be stored in the computer with the proper program being called for by the data tape recorded at CADDE. The magnetic-tape handlers A, B, C, and D, plus a separate tape handler associated only with the computer, may all feed data into the computer upon demand. The data tape will call for the proper program to process the data recorded on the tape. The data tape may also contain computer instructions to a limited extent. Indication of the first and last words of a reading is always recorded. In cases where it is known that bad or doubtful data words will be recorded, computer program modification codes are inserted in the words by means of a plugboard. This program modification (code-out) instructs the computer to calibrate the word in the normal manner but not to include it in any averages or ratios that the stored program may call for and to tag the computed value suitably so as to call attention to its doubtful status.

Data can also be fed into the computer by means of paper tapes. Some smaller facilities produce only paper tapes from AVD's. Some facilities produce both paper-tape and magnetic-tape data which must be correlated for terminal calculations. Both of these conditions are handled by feeding the paper-tape data into the paper-tape reader and processing them by means of the stored program. The second case is particularly interesting in that the paper tape calls for the magnetic-tape reading associated with it, and the computer searches until it finds the reading and proceeds with the processing. Thus, data from two different media are correlated and treated as if they came from only one.

The output of the computer is a Teletype high-speed paper-tape punch which produces tape at a rate of 60 characters per second.

The only other output of the computer at present is a supervisory Flexowriter which can be used for various bookkeeping, housekeeping, and trouble-shooting tasks.

The punched paper tapes are used to operate Flexowriters for written records or can be used to operate time base or two variable plotters for plotted records. The records are then delivered to the project engineers at the facilities. The Flexowriters are also used to prepare paper program tapes for the computer.

REMARKS

The CADDE system briefly described in this chapter has been in service for over 2 years. In that period the total unscheduled down time has amounted to less than 1 percent. The data loss due to malfunctions of all parts of the system has also been slightly less than 1 percent. The system is in operation 24 hours a day with preventive maintenance being carried out on the day shift when the facilities are not running. The demand load on the system has never approached its theoretical capacity except for brief 1- or 2-minute periods at widely scattered times. Maximum data recorded have been approximately 300,000 words in 1 week, but a 3-month average of approximately 150,000 words per week has been maintained.

The computer system described previously has been in operation for data processing for approximately 1 year. Unscheduled down-time figures are not available but are probably substantially higher than for CADDE. However, no harm has been done to the system because the computer is not an integral part of the recording system. Since the data are safely recorded on tape, even a major breakdown would only delay the feedback of the computed results to the facility. The goal of getting information back to the facility the day following the test has been substantially achieved.

With further experience and development of new techniques in program writing and hardware, it may be possible to put the computer "on line" as an integral part of the system and thereby feed back computed results within a few minutes.

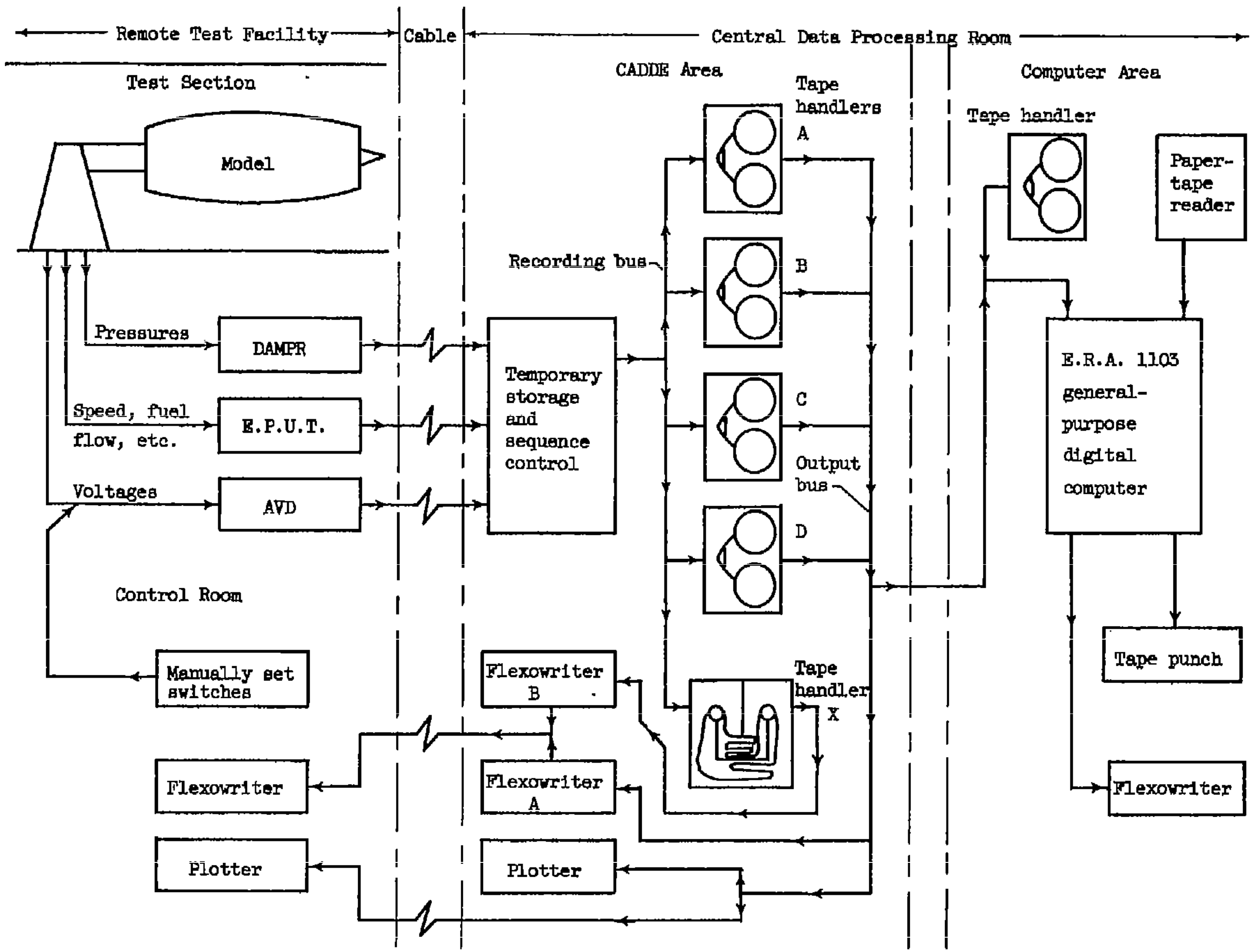

Figure 1. - Block diagram giving general description of data processing system.

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CHAPTER II

CENTRAL RECORDING SYSTEM

By Robert L. Miller

CABLE AND INTERLOCK SYSTEM

The basic logic followed in the operation of the central recorder is that only one facility will be recording data at any particular time. Lines in the cable connecting the various facilities to the central recorder may, for the most part, be shared as shown in figure 1. These lines fall into one of two classifications:

(1) Data input lines, which carry data information from the facility to the central recorder

(2) Control lines, which coordinate the measuring equipment at the facility with the central recorder

Data input lines are used by all facilities and, therefore, are common. Relay contacts in the data input lines at each facility are closed by the central recorder only when that facility is recording. These contacts prevent interference between facilities due to the common data lines.

Control lines must be individual to each facility in order to identify and control separately the measuring equipment at each facility.

A multiple relay interlock system at the central recorder handles "calls" placed at the facilities for the use of the recorder. A call, which is a request for recording, is initiated at the facility by depressing a pushbutton for that purpose. Calls are stored in order as they arrive. As one facility completes a data recording cycle, the facility whose call was next in line is connected to the recorder. A secondary function of the interlocks is to check the condition of various circuits in the recorder for normal operation. Should a circuit fail to operate when a call is placed to the recorder, the facility would not receive a "recorder ready" light indication in its control room, at which time corrective measures might be taken by personnel at the recorder.

RECORDING ON MAGNETIC TAPE

Data are recorded at the central recorder on a standard 1/4-inch-wide magnetic tape. Saturation, two-level-return, pulse recording is used on two tracks. A "south pole" magnetic field is recorded continuously until such time as a pulse is to be recorded. At that time, a maximum "north pole" magnetic field is recorded for the duration of the pulse. The magnetic tape is then returned to a maximum south pole condition until the next pulse occurs. Since the magnetic tape is forced into one of two conditions as it is recorded, it is unnecessary to erase the tape previous to re-recording.

Word Structure

Figure 2 shows a data word on magnetic tape. As previously mentioned, two tracks are utilized. A clock track, containing 32 equally spaced pulses or bits per word, marks 32 positions opposite which pulses can occur in the information track. The word is divided into three fields. The word number field and the editing and control code field each contain 8 bits. The data field contains 16 bits. Each field is further subdivided into groups of 4 bits per group.

The 4 bits within a group are assigned a value 8, 4, 2, and 1, respectively. A pulse or bit appearing in the information track, therefore, carries one of these values, as shown in figure 2. By adding the values assigned the bits within a group, the decimal equivalent of this binary coded decimal digit may be obtained. Conversion of the word shown to decimal digit form reads word number 38. The number in the data field, which is proportional to the quantity measured, reads 4875.

Words are spaced on magnetic tape one word length apart, a word length requiring about 3/8 inch.

Block Structure

A block of information, on magnetic tape, is defined as a series of words containing data from a common source, such as a voltage digitizer at a facility. All voltage measurements made at this facility would be recorded in one block. The first word of a block is numbered 01, and all words in the block are numbered consecutively thereafter.

A reading on magnetic tape would contain a series of blocks recorded from one facility. Figure 3 shows a typical reading containing five blocks in the sequence in which they are normally recorded. General information denotes a block of words containing the date, time, reading number, and any other pertinent information which might be needed to identify the reading.

The voltage block contains measurements from the output of the thermocouples, strain gages, or other voltage output transducers.

The frequency block contains measurements from the output of tachometer generators, flow meters, or other devices which are used to measure engine speed, fuel flow, or any other E.P.U.T.

The pressure block contains measurements made by the pressure transducing equipment connected by tubing to various pickups about the model or engine.

The last general information word in a reading identifies the end of a reading. The reading number is contained in this word.

SHIFT REGISTER AND INPUT SELECTION

Shift Register

An intermediate storage device called a shift register is used to assemble each word in preparation for recording on magnetic tape. In order to explain the operation of a shift register, a four bit register is shown in figure 4.

The shift register transfers information from parallel to serial, or serial to parallel, form. In figure 4 the register is connected as a parallel-input, serial-output device. The operation occurs in two steps. In the first step, through the parallel-input lines, the binary stages in the register which have an input signal are set up. As an example, the binary stages "4" and "2" might be set up.

In step two a series of events takes place. A gate, which is open when the "8" binary stage is set up, allows a clock pulse to appear at the serial output. This gated clock pulse is called an information pulse. Since the "8" binary was not set up when the first clock pulse occurred, no pulse appears at the output. The clock pulse also passes through a delay and then causes all bits in the register to shift to the left one stage. The "4" bit would now set up the "8" binary, which allows the gate to pass the next clock pulse. The timing diagram on figure 4 shows a sequence of four clock pulses, four shift pulses, and the serial-output information pulses.

In the central recorder, a thirty-two bit shift register is used to assemble the information in the word number, editing and control, and data fields in order to make up a word. This information is all fed into the register through its parallel input. A series of 32 clock pulses then causes the register to shift the information serially onto magnetic tape as shown in figure 5.

Input Selection

The shift register is the central point at which all words are assembled in preparation for recording. Each of the devices used to measure the various quantities, therefore, must present its output in a form acceptable to the shift-register parallel input. A bank of multiple contact relays connects the shift-register input to the various measuring devices, as shown in a simplified diagram in figure 6. The input selector is advanced one step in the counter-clockwise direction by the device to which it is connected after this device has completed the generation of a block of words.

On step one of the selector, a block of general information words would be presented sequentially to the shift register. The 16 bit data field for each word would be supplied by the general information generator. Editing and control and word numbering, each containing 8 bits, would be presented by their respective generators.

On step two, the data and editing and control fields of the voltage block, totaling 24 bits, would arrive over the cable and be fed into the shift register.

On steps three and four, the editing and control field again originates in the editing and control generator, with the 16 bit data field being supplied by the two temporary storage units containing frequency and pressure measurements. Word numbering for all blocks is supplied by the word number counter and is reset to zero after each block is complete.

General Information Generator

This device is used to generate a pattern of bits by energizing a single wire. A simplified circuit is shown in figure 7. With the commutator on position 1, a current pulse passing through the single wire of the "1" transformer will cause a voltage pulse at the output of that transformer. However, if a wire passing through two transformers is pulsed, as on position 2, an output appears at both transformers. Thus, any combination of bits may be generated by pulsing a single wire passing through the appropriate transformer cores.

In the transformer translator used in the central recorder, 16 transformers are wired in various patterns to generate the 16 bit data field of general information words. The output of each of the 16 transformers is connected to the shift-register parallel input through the input switching. Various arrangements of commutators are used to select the particular pattern of bits to be generated.

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A reading number counter is used to keep a running account of the number of readings taken by a given facility. Four ten-position stepping switches are cascaded in such a manner that the advancing of the first stepper through ten positions advances the next stepper one position. This is carried out for the four steppers, so that the combination will count up to 9999 steps of the first stepper without repeating a step on the fourth. The ten positions of each of the four steppers are wired through the transformers in the 16 bit translator in a manner similar to that shown in figure 7.

A 24-hour digital clock, made up of stepping switches, is used to select the appropriate transformer primary windings for the recording of time on magnetic tape. The date, at the time of recording, is generated in a similar manner. Two numbers, 7777 and 8888, are recorded in the general information block to check the operation of the shift register. These two numbers contain all bits in the data field of the register. The barometric pressure, which is read from a barograph, is manually set in on switches at the CADDE console. These switches select the appropriate pattern of bits for this word in the general information block.

Certain general information words do not change often. An example of this might be the program number. This number identifies the facility at which the data originated and the arrangement and size of the blocks within a reading. This program number seldom changes more often than once every few weeks. The translator is manually wired for this word. A single wire is merely threaded through the proper transformer cores and connected to a plug-in connection.

Figure 8 shows how general information words are generated sequentially. The data field, programmed through the plugboard, is generated a word at a time by the sixteen bit transformer translator as the general information commutator advances from step to step. At the same time, the editing and control field, programmed through the plugboard, is being generated in a similar manner. The word number field is supplied by the word number counter, which is advanced on each step of the commutator.

Voltages

Voltages, which are usually the output of thermocouples or strain gages, are measured at each facility by the Automatic Voltage Digitizer. The operation of this instrument is described in chapter III. The output of the AVD is in the 24 bit form required for input to the central recorder. The digitized voltages are transmitted one at a time over 24 wires to the central recorder. The coding field of the voltage word is supplied over eight wires from the digitizer and is selected individually for each word by a plugboard and commutator at the digitizer. Word numbering at the central recorder is restarted for the voltage block and is advanced as the digitized voltages arrive at a rate governed by the particular digitizer.

In order to maintain the proper word spacing on magnetic tape during the voltage recording cycle, it is necessary to operate the tape handler on a start-stop basis for digitizers operating at a speed less than 20 words per second. The tape is started, one word is recorded, and the tape is stopped until the next digitized voltage arrives. Only at the normal recording rate of 20 words per second can the tape be allowed to run continuously.

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Frequencies

Frequencies are measured by electronic counters at the central recorder. One counter and one twisted pair of lines in the cable are required for each frequency word. A measurement is made by connecting the counters to frequency sources for a precisely measured interval. At the end of this time, a count proportional to frequency is stored in each counter. Counter output is in 16 bit binary coded decimal form and is presented to the shift register one channel at a time by means of commutators. Coding is generated and inserted in a manner identical to that used with general information. Word numbering is advanced by the channel commutators. Chapter IV covers the operation of this input device in detail.

Pressures

Pressures are measured at the facilities. A pulse is transmitted over the cable at a time, proportional to the pressure measured, after a reference time. Figure 9 shows three channels for transmitting pulses. Time delay is measured with respect to a common reference time for all channels by a common electronic counter. The number appearing in the counter at the end of delay for a particular channel is recorded in a 16 bit magnetic-core memory channel. Memory capacity is 300 channels. After all measurements are made and the memory is loaded, it is read out, one channel at a time, into the shift register. Coding is generated and inserted in a manner identical to that used in general information. Word numbering is advanced by the channel steppers. A detailed section on this input device is presented in chapter V.

CONTROL BOARD FUNCTIONS

A four-facility standby system is in operation at the central recorder. As previously mentioned, only one facility can record at a time. However, as many as three other facilities could be running tests and taking data as the recorder is available. The average time for a recording sequence is 30 seconds. Thus, the waiting time for recorder availability is negligible for a steady-state measuring system. Four magnetic-tape handlers are used in conjunction with four plug-type removable control boards. The plugboard has three functions: (1) Individual controls identified with the facility are connected to the recorder, and a tape handler is selected for use by that facility only. (2) Block sequence and number of words per block on magnetic tape are programmed. (3) General information word sequence, along with the editing and control codes for all blocks except temperatures, is programmed.

A typical recording sequence would be carried out as follows: A control board, plugged according to a predetermined program, has been inserted in the holder under the tape handler with which it will be associated. When the facility is ready to take a data measurement, a call is placed to the central recorder by means of a pushbutton at the facility control room. As soon as the recorder has served all previously placed calls, the call is accepted. The facility is notified by means of a light indicator that the recorder has been connected to its controls and measuring station. At this time, depressing the call pushbutton will start a data record cycle.

Pressure and frequency measuring equipment immediately begin measuring and storing numbers proportional to their inputs in the magnetic-core and vacuum-tube memories. This portion of the measurement cycle lasts approximately 10 seconds. Simultaneous with the start of this cycle, the general information generator, programmed through the plugboard, generates a block of words that are recorded sequentially on magnetic tape. Control of the recorder, which is programmed through the plugboard, is now turned over to the AVD. Word numbering starts over again as the first digitized voltage is received at the recorder. Voltage words, which include the code field, are transmitted over the cable as each voltage is measured. This recording cycle requires approximately 1/20, 1/5, or 1 second per word, depending upon the particular digitizer. The tape handler operates on a start-stop basis for digitizers operating at a speed less than 20 words per second to provide even word spacing on magnetic tape. At the end of the voltage block, control of the recorder is transferred back to the control board at the central recorder. A read out of the vacuum-tube memory containing frequency words is now commanded by the plugboard. A few seconds delay might precede this command if the pressure and frequency measuring cycle is incomplete. The frequency block is then recorded on tape with code fields being supplied by the plugboard for each word. At the end of this block, the plugboard commands a read out of the pressure words temporarily stored in the magnetic-core memory. Codes for these words are again supplied by the plugboard, and word numbering starts over again.

General-information, frequency, and pressure words are all commutated and recorded at a rate of 20 words per second. The tape handler runs continuously during these cycles. At the end of the pressure block, the control board commands the general-information generator to record a one-word block containing the reading number and an end-of-reading code.

This completes a recording sequence. All memories and control circuits are cleared for another recording. The recorder will now accept a call from another facility if one has been placed.

Figure 10 shows two of the four tape handlers together with the two associated control boards. One of the control boards is open, showing the plugged wires connecting the various circuits. An over-all photograph of CADDE is presented in figure 11.

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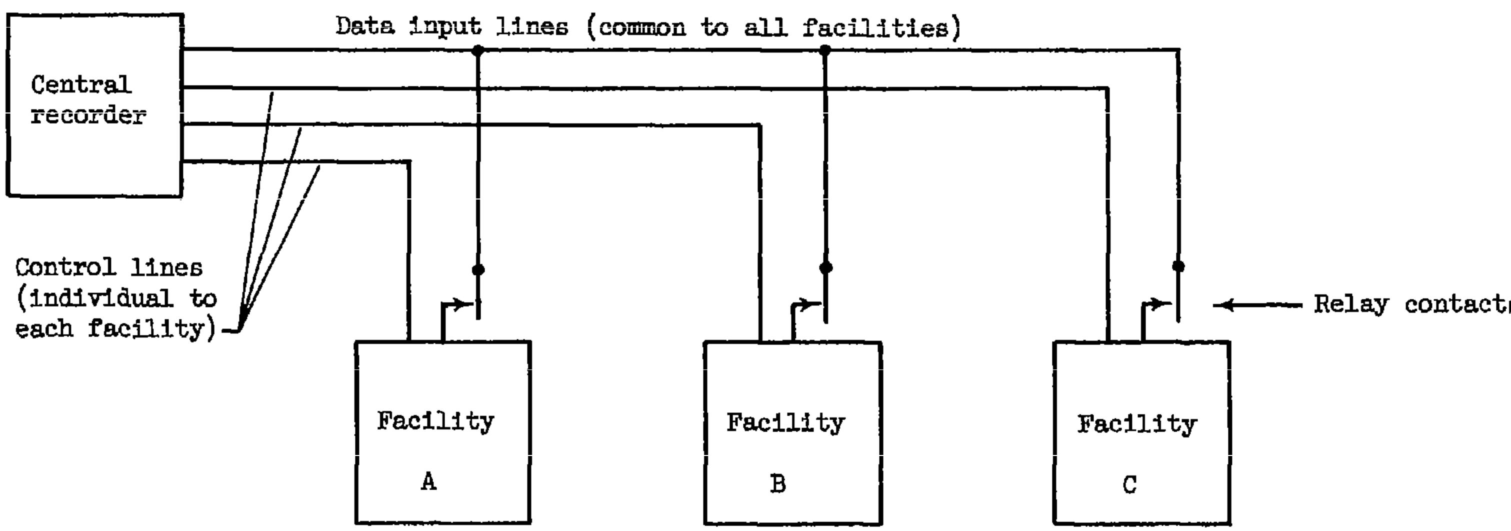

Figure 1. - Interlocks and cable system.

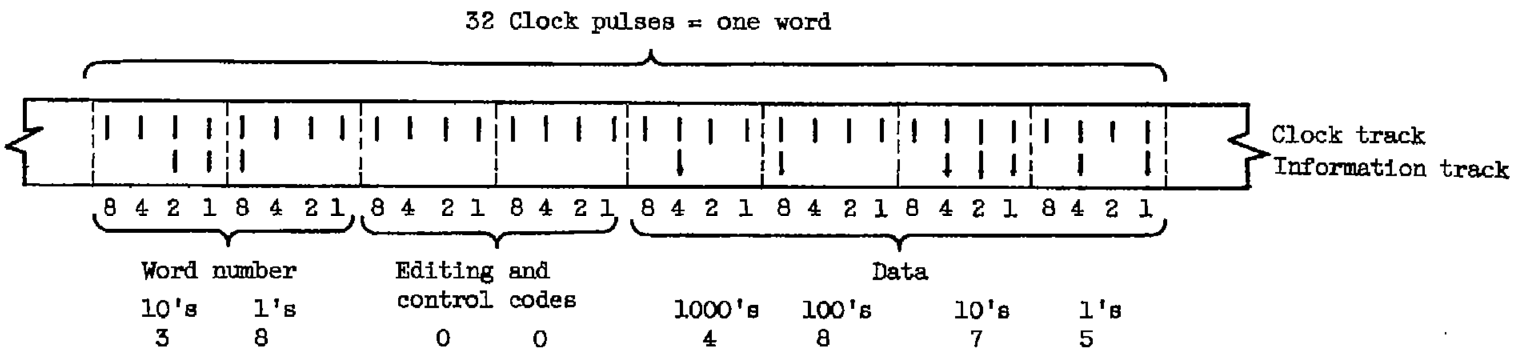

Figure 2. - Word structure on magnetic tape.

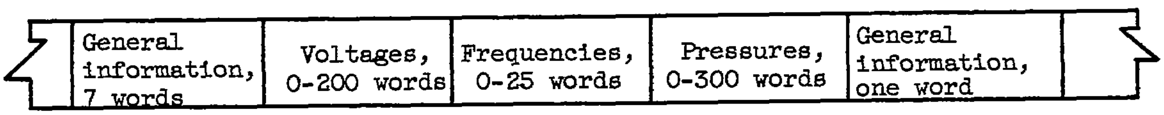

Figure 3. - Reading, consisting of five blocks, on magnetic tape.

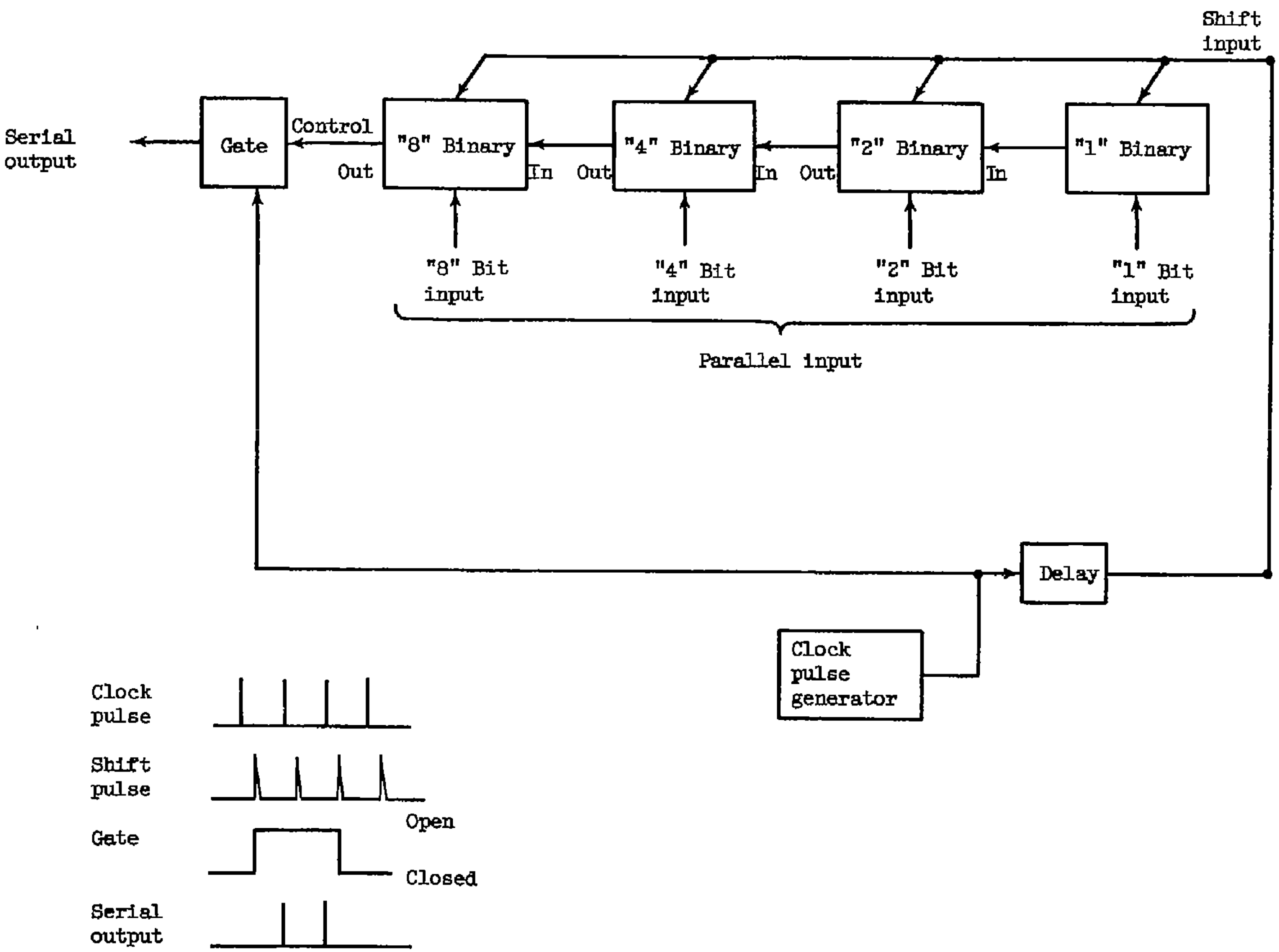

Figure 4. - Four bit shift register.

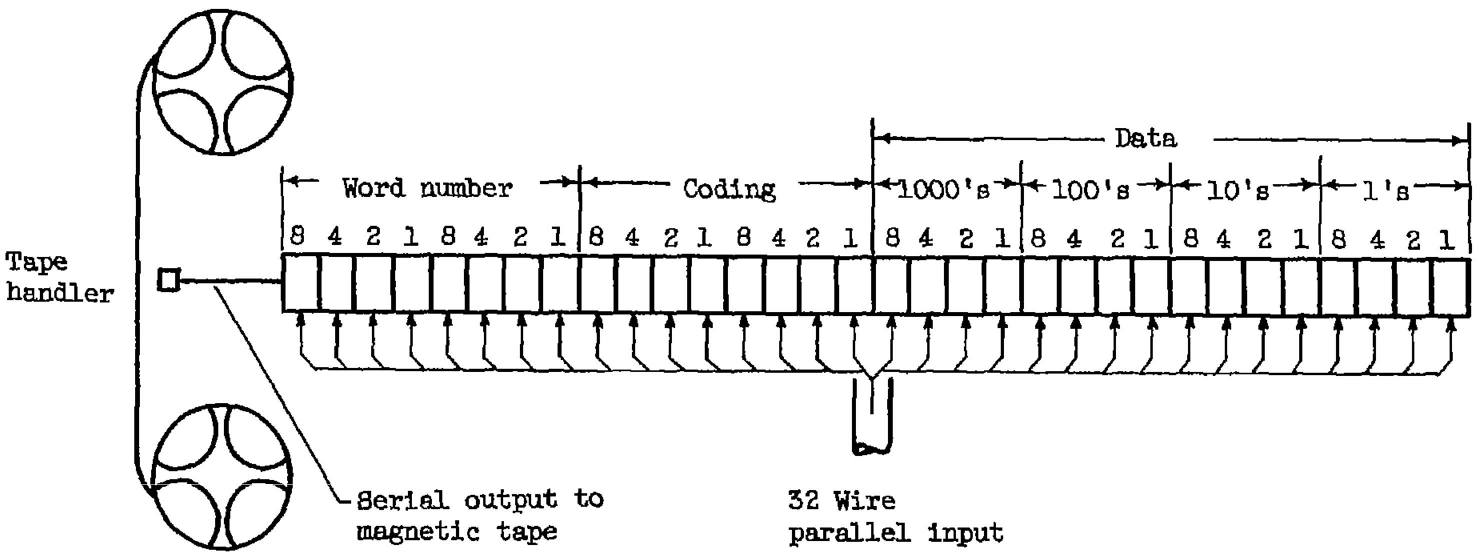

Figure 5. - Thirty-two bit shift register.

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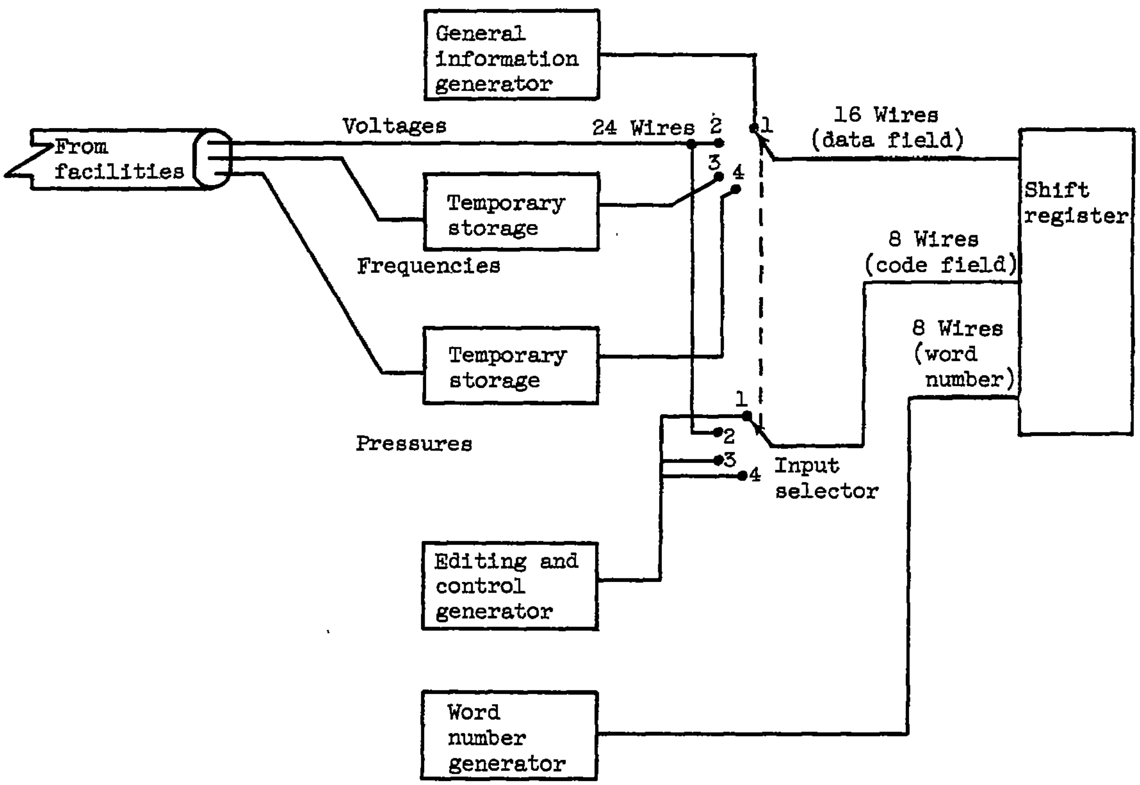

Figure 6. - Input selection.

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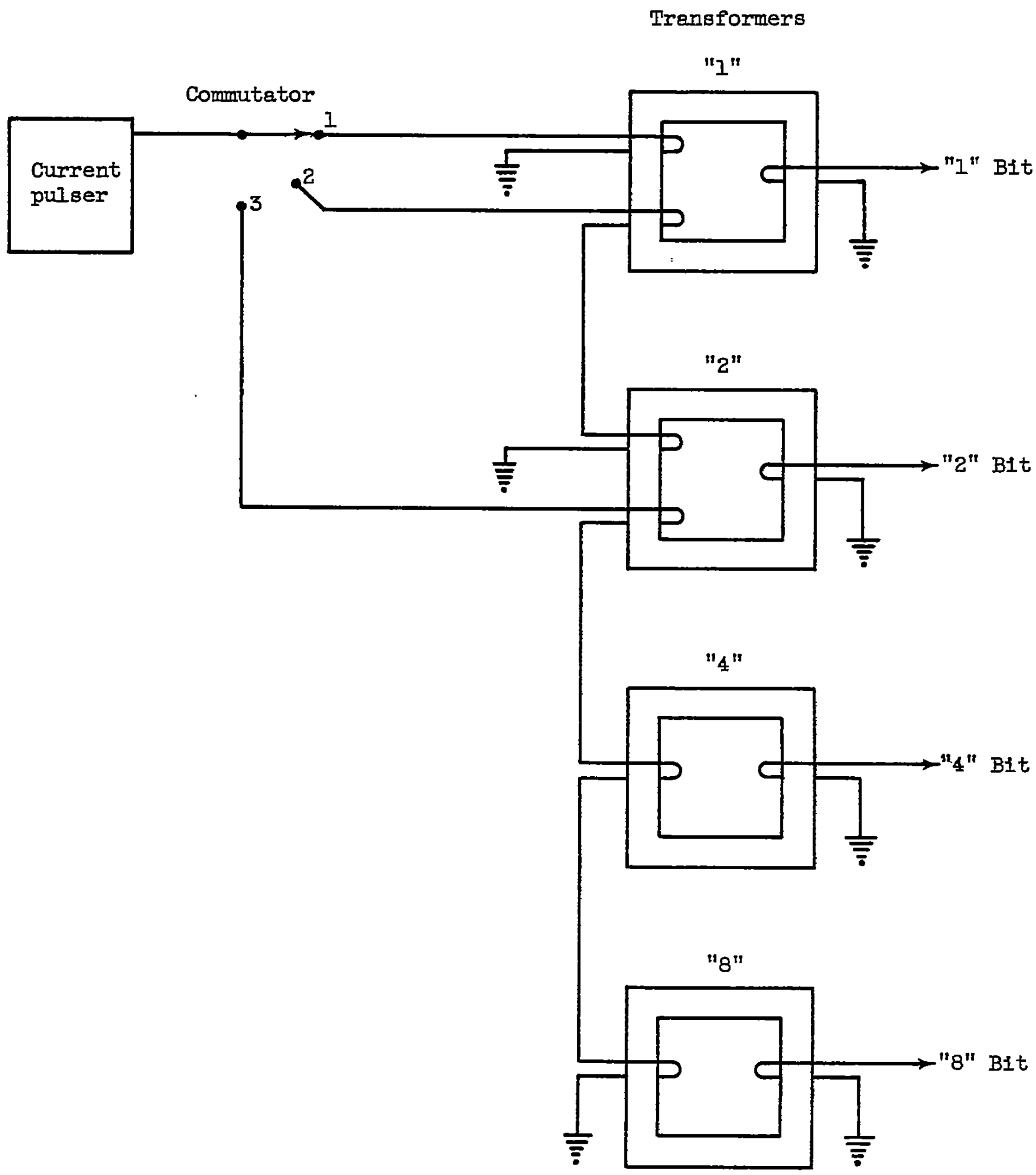

Figure 7. - Four bit transformer translator.

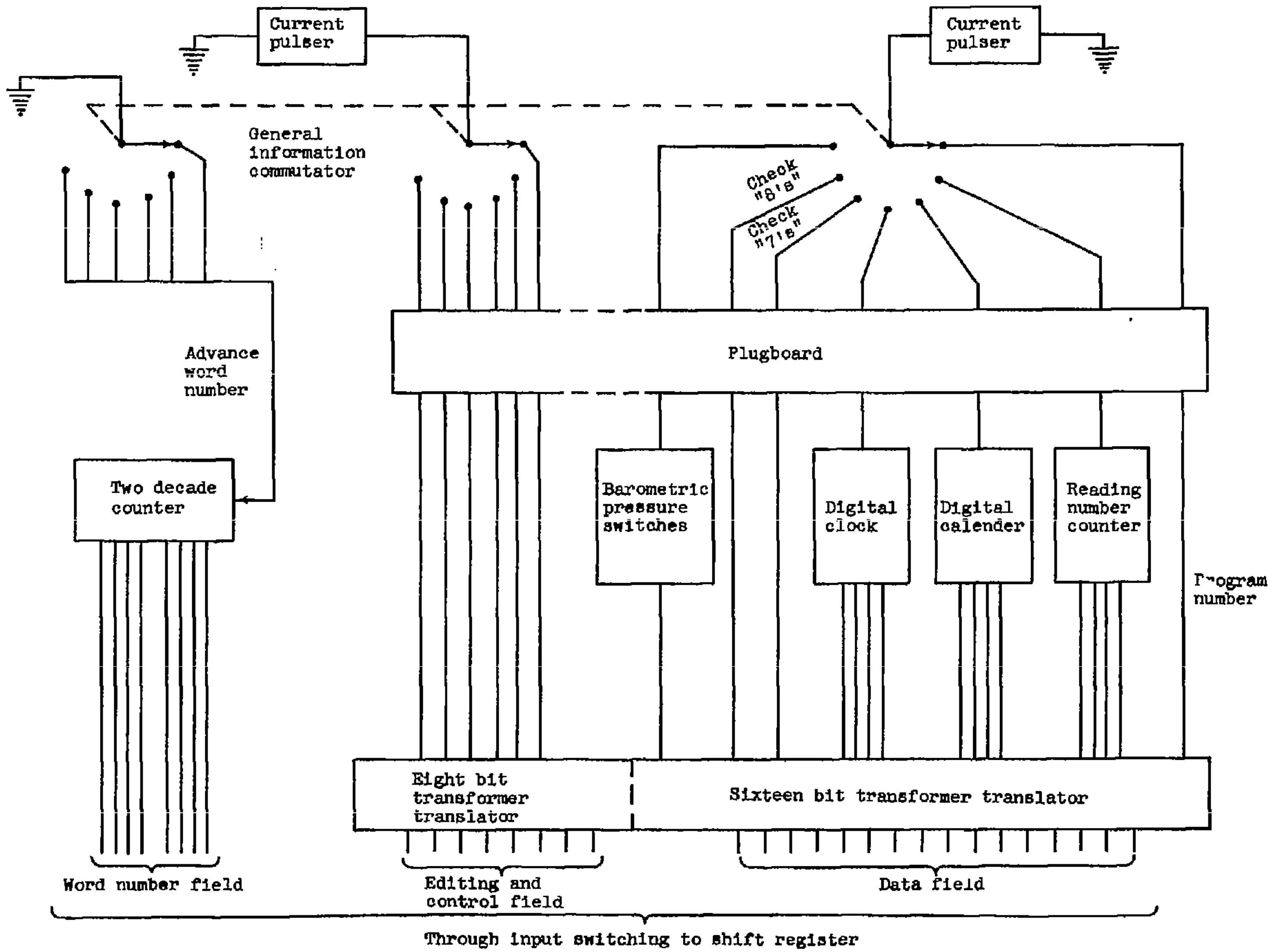

Figure 8. - General information sequential word generation.

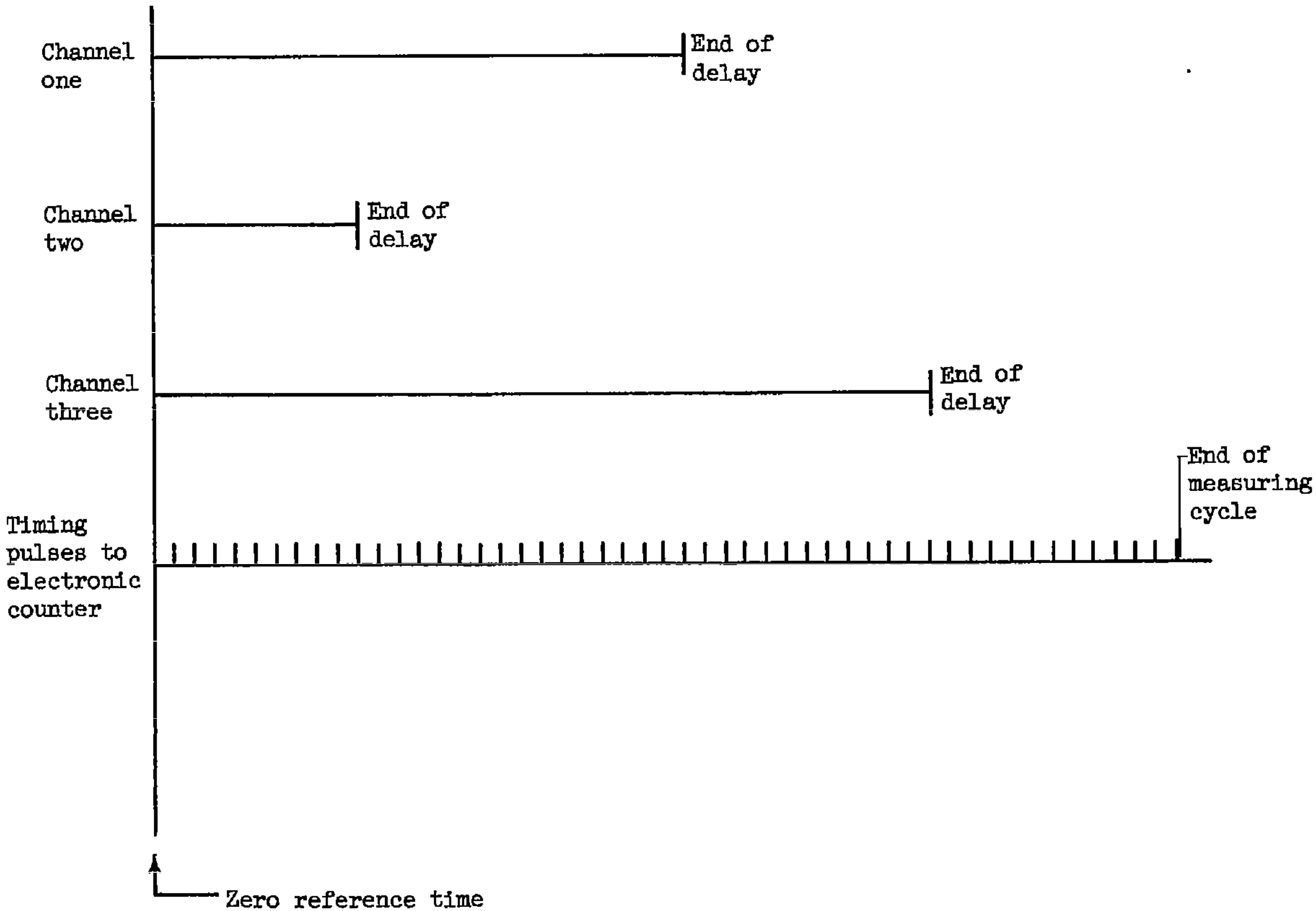

Figure 9. - Pressure measurement cycle.

Figure 10. - Magnetic-tape handlers with control boards.

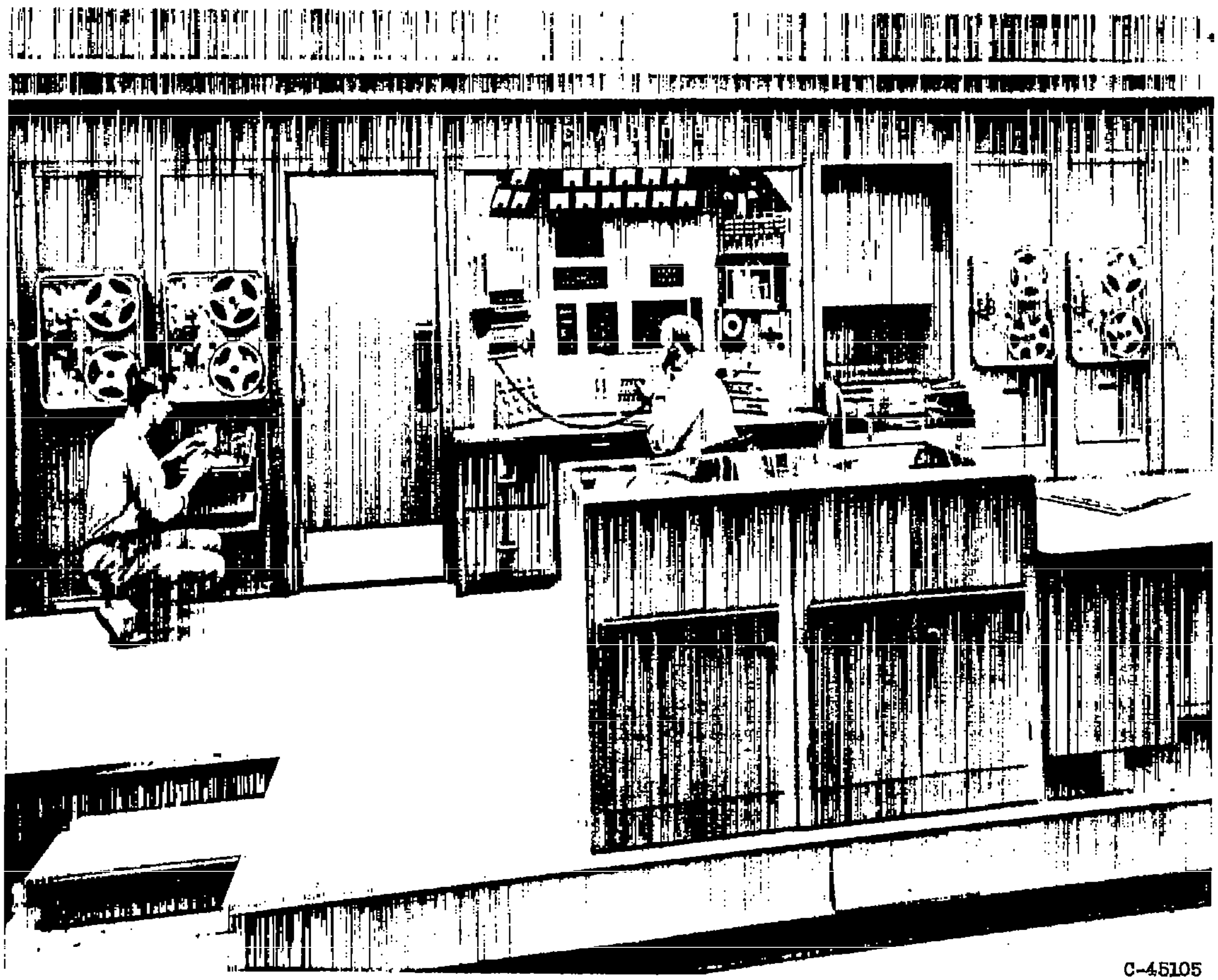

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Figure 11. - Central data recorder.

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CHAPTER III

AUTOMATIC VOLTAGE DIGITIZERS

By Leonard Jaffe and Richard L. Smith

In order to facilitate the recording and processing of data from transducers such as thermocouples, strain gages, and shaft position indicators, three types of instruments have been developed at the Lewis laboratory for converting voltage-type data to a digital form.

Type I, which was developed first, and which has been in use at the Lewis laboratory for over 5 years, is an automatic relay potentiometer that has a punched paper-tape output. This instrument is a complete data recording unit in itself. Its punched paper-tape output is processed by the central data computer. Direct-current voltages as low as 20 millivolts full scale can be read and recorded to an accuracy of ± 0.15 percent of full scale at a rate of 1.5 readings per second. Voltages of either polarity may be measured, and the input to the instrument is completely isolated from ground. This type I digitizer is used in small facilities which do not take a sufficient quantity of data to justify higher speed systems.

The type II digitizer, in use at this laboratory for 2 years, is essentially a modification of the type I digitizer and operates at a higher speed. The digital output of this unit consists of electrical signals which are fed over telephone lines to CADDE where they are recorded on magnetic tape. The input voltage specification and accuracy are identical to those of the type I digitizer; however, this system will read voltages at the rate of five readings per second. This unit is used in facilities which have a large number of steady-state voltage data points to take in a limited time. An additional advantage over the type I digitizer is that voltage data can be recorded along with other digitized forms of data on the same magnetic tape at CADDE. This simplifies the correlation of data for computing purposes.

The type III digitizer is a completely electronic voltage digitizer, a development made possible by recent improvements in direct-current amplifier design. Two versions of the type III digitizer have been developed. The type III(a) will read and record voltages at a rate of 40 readings per second and was built specifically for recording slow transient data. The type III(b) reads and records voltages at half the rate of the type III(a) and is used for recording large numbers of steady-state voltages. The speed of the type III(b) unit is such that as many as 200 voltages can be recorded during the time required by the DAMPR system for the scanning of pressures. Both type III digitizers accept voltages as low as ±10 millivolts full scale with an accuracy of ±0.15 percent of full scale, and their outputs are recorded on magnetic tapes at CADDE.

TYPE I DIGITIZER

The type I voltage digitizer records on six-hole punched paper tape. The information on the tape can be printed automatically on a typewriter as fast as it is punched on the tape. As many as 200 channels of data can be recorded. Preceding each 200-channel reading, three to six words of preliminary data are automatically punched into the tape. One of these words contains a reading number which advances each time the start button is pressed. The other pre-data words contain information set in on manually operated switches and can indicate test facility, test number, data, or other pertinent information. Each word on the tape following the three to six pre-data words represents one digitized voltage.

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Each word on the tape is composed of eight characters as shown in figure 1. The first two characters are numbers indicating the serial number of the word within a reading. This two-digit number is referred to as the channel number. The third and fourth characters in the word are used for computer instructions and editing purposes. Characters five, six, and seven are actual data, a three-digit number indicating the percentage of full-scale millivolts (or pre-data information if the word is a pre-data word). The eighth character is a space or carriage return signal to the typewriter.

Principle of Operation

This type I digitizer is an automatic potentiometer which measures voltages by comparing them with a variable reference voltage. The difference between these two voltages is amplified, and the amplifier output is used to change the reference voltage until it equals the unknown voltage.

A simplified diagram of the potentiometer circuit for the range of 0 to 10 millivolts is shown in figure 2. In order to bring the instrument to balance quickly, 12 high-speed relays are used in the reference-voltage circuit. The number beside each of the 12 resistors represents the current in microamperes which flows through each resistor when its series relay contacts are closed. The sum of these currents flowing through the 10-ohm resistor develops the reference voltage. By closing various combinations of the 12 relay contacts, any value of total current between 0 and 999 microamperes to a resolution of 1 microampere can be obtained. In this way, any value of reference voltage can be produced between 0 and 9.99 millivolts to a resolution of 0.01 millivolt.

In operation the 12 relay contacts are closed one at a time, from left to right, by a master stepping switch. Immediately after the first one closes, the relay contacts in series with the amplifier input open, developing a signal pulse that is positive if the reference voltage is
4256 less than the unknown voltage and negative if the reference voltage is greater. A positive pulse causes the first thyratron tube, which has now been connected to the amplifier output, to fire. This operates a relay which holds the first reference-voltage relay closed. If the reference voltage was greater than the unknown voltage, the first thyratron would not have fired, and the first relay would have opened when the master stepping switch moved to the second step. The same sampling process takes place on each of the 12 steps.

Figure 3 indicates how the reference voltage approaches and finally equals an arbitrarily selected unknown voltage during the 12 sampling steps. The unknown voltage, in this case 6.75 millivolts, is indicated by a dotted line. The shaded areas identify steps on which a thyratron has fired.

In order to make one reading, the master stepping switch moves through 12 steps, an operation which takes 2/3 second. After it has completed this cycle, certain of the 12 thyratrons will have fired and corresponding reference-voltage relays will be closed so that the potentiometer is in balance. The correct voltage reading is now indicated by the conducting or nonconducting state of the 12 thyratrons. Relays in the plate circuits of the thyratron tubes transfer their information directly to the tape punch. In order that the tape punch can operate continuously, there are two sets of 12 thyratrons, one of which obtains its information from the potentiometer while the other is transferring its information to the tape punch. Each set of thyratrons receives its information from alternate channels.

Refinements are incorporated in the voltage reference circuit which is shown in figure 4. 1.5-Volt dry cells comprise the voltage source which is periodically standardized manually by using a standard cell and galvanometer incorporated in the circuit.

Provision is made to keep the current from the direct-current voltage source constant regardless of the positions of the relay contacts. This is done by using a second bank of 12 precision resistors in parallel with the standardized direct-current voltage. These resistors are identical in value with the resistors in figure 2. The normally closed contacts of the 12 relays, whose normally open contacts are shown in figure 2, are in series with the 12 resistors in this second bank of resistors, so that the total current flowing through both banks is always 999 microamperes. These 24 resistors and the 12 normally closed and 12 normally open relay contacts are shown in figure 4.

The 10-ohm resistor across which the reference voltage appears can be divided in two parts to enable the instrument to read negative voltages. These resistors are represented by R1 and R2 in figure 4. 4256

Detector Circuit

Because negative signal pulses are always followed by a small positive voltage overshot, a simple amplifier feeding directly to the stepping switch, as shown in figure 2, cannot be used. The detector circuit used in the digitizer overcomes this difficulty. As shown in figure 4 the output of the first stage of the amplifier is divided into two parts, one that passes through a single stage of amplification to multivibrator A, and the other that passes through two stages of amplification to give a phase inversion of the voltage pulse to multivibrator B. The function of the one-shot multivibrators, A and B, is to pass uniform triggering pulses to thyratrons A and B. Thyratrons A and B are connected in such a way that if A fires B cannot fire, and if B fires A cannot fire.

The stepping switch is connected only to thyratron A so that the thyratron register receives no pulse if thyratron B fires. Thus, if the output of the first stage is a positive pulse followed by a small negative overshoot, multivibrator B receives a positive pulse before multivibrator A and thyratron B will fire, blocking out A, so that none of the 12 thyratrons in the thyratron register receive a voltage pulse. In the other situation, that of a negative pulse followed by a positive voltage overshoot, multivibrator A triggers first, firing thyratron A and thus causing one of the thyratrons in the thyratron register to fire.

Immediately after either of the thyratrons fires, plate voltage is removed from both to prepare them for the next signal pulse. In order that the detectors will ignore switching transients, plate voltage is not applied to the thyratrons until immediately before the next signal pulse so that the detector is inactive about 95 percent of the time.

Operation of Complete System

Figure 5(a) shows a simplified block diagram of the complete potentiometer. The master control is a self-energized 10-bank telephone-type stepping switch. It controls a stepping switch which connects the input thermocouples consecutively to the comparing circuit. This stepping switch also supplies channel identification information through the coder. The amplifier is shown supplying information to the upper thyratron and relay register. While this is taking place, the lower thyratron and relay register is reading out its previously stored information to the tape punch. As soon as the tape punch has received all the information from the lower thyratron and relay register, the information is wiped off by removing plate voltage momentarily from the lower register to prepare it for receiving more information from the amplifier. The relays in the thyratron and relay register recode the information from the 1-, 2-, 2-, and 4-code, as it appears on the thyratrons, to the 1-, 2-, 4-, and 8-code to conform with the code used by CADDE. The programming coder allows the tape punch to receive information from the channel identification coder and relay registers in the proper sequence.

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Physical Arrangement

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A photograph of the type I digitizer is shown in figure 5(b). The panel at the top of the left cabinet contains the preliminary data unit. Information can be set into the six pre-data words by means of the 18 dials on the front. Reading number, which advances once each time the operating button is pushed, appears on the third pre-data word and is indicated by the 12 lights on the pre-data panel. The three panels below the pre-data panel conceal the 200-channel switching circuit and coding relays. The plugboard for controlling the operation of the coding relays is mounted at the bottom of this cabinet. The top three panels at the right conceal the potentiometer and associated circuitry. The panel below these contains the galvanometer and controls for manual voltage standardization. Power supplies are mounted at the bottom of the right cabinet. The Flexowriter and paper punch normally used with the digitizer are shown at the right of the cabinets.

TYPE II DIGITIZER

The type II digitizer consists of four type I digitizer balancing circuits connected in such a way that they balance on four voltage readings simultaneously and then record their readings sequentially on magnetic tape. Since record time is short compared with balance time, this instrument can read and record at a rate approaching four times that of the type I digitizer, actually about five readings per second. The maximum number of inputs available is 200.

A block diagram of the type II digitizer is shown in figure 6. To initiate the operation of the instrument all four potentiometers are started on their first voltage measurement, and output switch A is closed.

As soon as potentiometer A has come to balance, the output is recorded on magnetic tape, output switch A opens and B closes, and potentiometer A starts to balance on its second voltage measurement. As soon as output switch B is closed, the first potentiometer B measurement is recorded, assuming that B has come to balance. If not, the tape handler waits until B has come to balance before recording the measurement. Output switch B then opens, output switch C closes, and potentiometer B starts to balance on its second voltage measurement. This cycle continues until all four potentiometers have converted and recorded all the voltages which have been programmed. Since the four potentiometers work independently of each other, each one may have a different voltage range. 4256

A photograph of the type II digitizer is shown in figure 7. The four identical balancing circuits are in the cabinet at the left. The top panel of the right cabinet conceals the input voltage switching circuitry and relays used for control and coding. Beneath this is the panel for standardizing the reference voltages of the four balancing circuits. Below the standardizing panels are the patch board and power supplies.

TYPE III(a) DIGITIZER

The type III(a) medium-speed voltage digitizer was designed to convert voltages to a digital number at a rate that would allow the measurement of slow transient data. A conversion speed of 40 samples per second with an accuracy of ±0.15 percent of full scale and a full scale of ±10 millivolts was established as the requirement of this instrument.

Figure 8 shows a block diagram of the type III(a) medium-speed voltage digitizer. The inputs from 50 voltage sources are presented to two telephone-type stepping switches. In order to sample these inputs at 40 samples per second and still make use of conventional stepping switches, the two switches are advanced alternately. The outputs of these switches are connected to identical direct-current amplifiers A and B, which have a voltage gain of 100 and bring the voltage levels to ±1 volt full scale. The output voltages of the two amplifiers are connected alternately to the digitizer, which converts these voltages to digital numbers at a rate of 40 words per second and sends them over telephone lines to CADDE where they are recorded at this rate on magnetic tape.

Control

The control circuitry for the instrument is operated by synchronizing pulses originating from a crystal-controlled oscillator at CADDE. These pulses are fed to two gate circuits which are operated in such a way that alternate pulses control each of two multivibrator circuits driving stepping switches SSA and SSB (fig. 8). The CADDE pulses are used also to trigger the digitizer.

Operation of the high-speed relay K1, which connects the analog-to-digital converter to alternate amplifiers, is initiated through the control circuit by a digital converter pulse indicating the end of a conversion period. In this way, switching occurs as soon as possible after completion of a voltage conversion.

Amplifiers

Amplifiers A and B are commercially available chopper stabilized direct-current amplifiers. Their specifications include an equivalent input drift of less than 5 microvolts and an equivalent input noise less than ±5 microvolts below 750 cycles. The input to these amplifiers was unbalanced, and it was necessary to disconnect the input and output common wire from ground in order to read inputs from grounded thermocouples.

Analog-to-Digital Converter

The basic analog-to-digital converter used in this system is a commercial Delaware Products Digital Voltmeter Model 215 which was modified at this laboratory. Voltages are measured by obtaining a time interval proportional to the voltage being measured and then counting the pulses of a fixed-frequency oscillator during this time interval. The number of counts obtained is proportional to the voltage being measured. The time interval is obtained by the use of a linear voltage sweep whose slope is accurately controlled. For example, the time interval could start when the sweep passes through zero, and the time interval would end when the sweep is equal to or has some proportion to the voltage being measured. The block diagram of the analog-to-digital converter (fig. 9) indicates that the input to the E_o comparing amplifier is the linear voltage sweep (generated by the sweep generator) alone, while the input to the E_x comparing amplifier is the sum of the linear voltage sweep and the voltage being measured E_x. The input to the E_o comparing amplifier changes sign when the sweep passes through zero. The input to the E_x comparing amplifier changes sign when E_x is equal to or has a fixed proportion to the sweep voltage. A change in polarity of the output of either the E_o or the E_x comparing amplifier opens the polarity sensing gate which allows pulses from the oscillator to accumulate in the counter. The polarity change in the output of the remaining amplifier closes the polarity sensing gate and thus stops the trail of pulses, and the counter then contains a number proportional to the time between the coincidence of the sweep with zero and the coincidence of the sweep with the voltage being measured. This number, consequently, is proportional to the voltage being measured. A circuit (not shown) that senses which of the two comparing amplifier outputs reversed signs first is used to indicate the polarity of the unknown voltage.

The modified version of this analog-to-digital converter has an input voltage range of ±1 volt and can measure these voltages to an accuracy of ±0.1 percent. Output connections were made to each stage of the counters to facilitate transmitting the stored number over telephone lines. The common side of all circuits in the converter, with the exception of the counter, was disconnected from the chassis to make it possible to read inputs from grounded thermocouples and strain gages by using a common power supply. The counter portion of the analog-to-digital converter must be connected to CADDE equipment and thus must have a grounded common wire. This difficulty was overcome by capacity-coupling the polarity sensing gate and counter common circuit for transmission of counter advance pulses and by transformer-coupling counter reset pulses.

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The handling of voltages in the microvolt region plus the floating of a substantial portion of the instrument above ground created problems. Gold-plated stepping switches were used to make the switching of these low level inputs possible. These switches had to be modified by adding extensive magnetic shielding to reduce induced noise from the operating coils. In order to minimize 60-cycle noise, which is aggravated by the floating ground system, isolation transformers were used to supply power to the amplifiers and digitizer. To minimize noise further, 400-microfarad nonpolarized condensers were used across each input.

A patch board is used to provide flexibility in the input system and to make possible the insertion of some computing instruction along with the data on the record. All inputs are brought into the patch board where they may be individually patched to any stepping-switch position. Provision is also made for paralleling any number of stepping-switch positions with any given input. Patch cords with gold-plated connectors are used to make all connections on the patch board to ensure low-resistance circuits at low-level voltages. A computer instruction code can also be selected and inserted along with the recorded data in any or all of the 50 words by means of the patch board.

A photograph of the type III(a) digitizer is shown in figure 10. At the top of the racks are the two direct-current chopper stabilized amplifiers. Below these are the analog-to-digital converter, control circuitry, and the control panel, in that order. Below these are the stepping switches used to commutate the inputs and the patch board, and, at the bottom of the rack is the power supply.

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TYPE III(b) DIGITIZER

The type III(b) medium-speed voltage digitizer was designed to convert steady-state direct-current voltage to digital numbers at a rate which would allow the measurement of a maximum number of voltages without slowing the data recording time of CADDE. A conversion speed of 20 samples per second, or half the speed of the type III(a) digitizer, was found to be adequate for measuring 200 voltages in the time consumed by the DAMPR pressure scan. Accuracy is ±0.15 percent full-scale voltage for a full-scale range of ±20 millivolts.

Figure 11 shows a block diagram of the type III(b) digitizer. The 200-input switching circuit consists of eight 25-position telephone-type stepping switches. Amplifier A (Offner Amplifier Model 190) is a commercially available chopper-type direct-current amplifier having a balanced input. Amplifier B (Kintel Amplifier Model 111AF) is a chopper stabilized-type direct-current amplifier used as a buffer between amplifier A and the analog-to-digital converter. The analog-to-digital converter is the same as that used in the type III(a) digitizer. The control circuit operates the switching circuit and analog-to-digital converter in synchronism with pulses from CADDE.

Figure 12 shows a photograph of the type III(b) voltage digitizer. The upper portion of the left cabinet contains the switching circuitry to switch the 200 input voltages and coding and control relays. At the bottom of the cabinet is a patch board used to insert computer instruction codes, select proper cold junction circuits, and return the equipment to its standby condition after recording the desired number of readings. The right cabinet contains, from top to bottom, the direct-current amplifiers, the analog-to-digital converter, the control circuit, and the power supply.

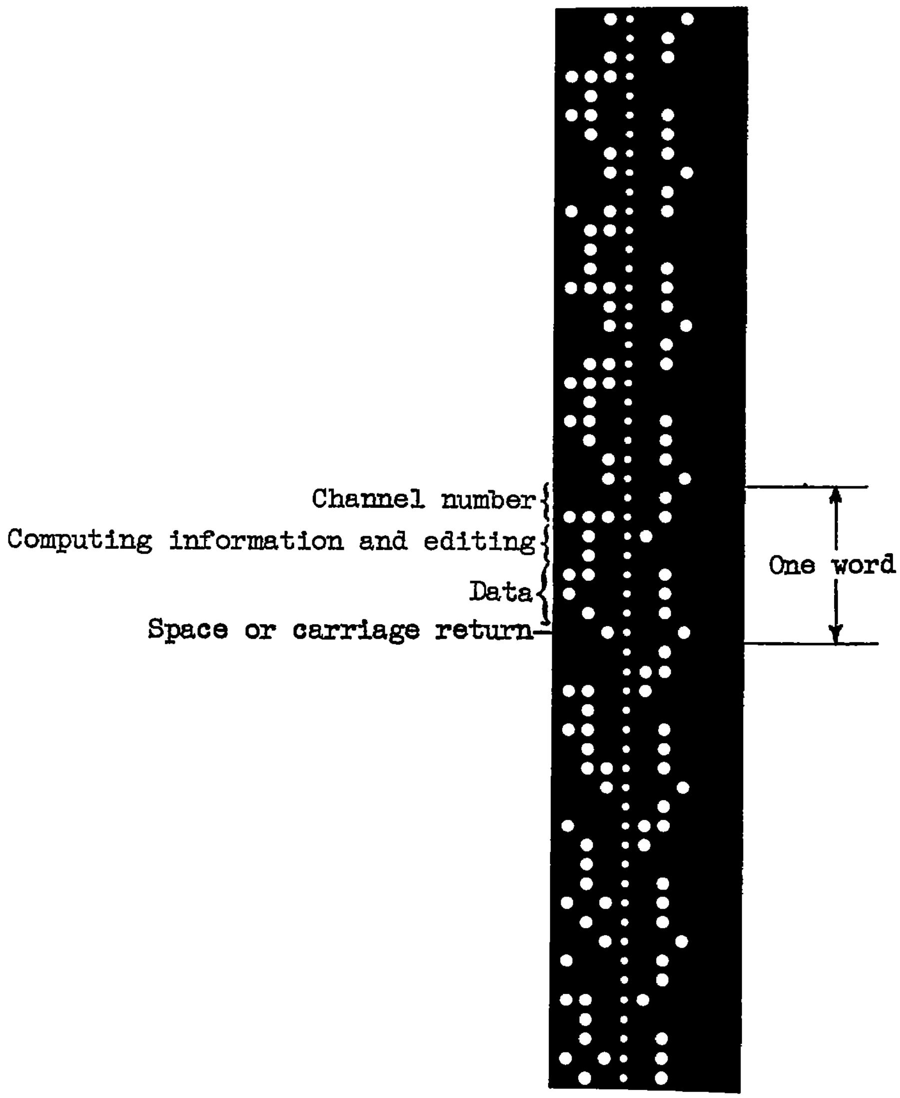


Figure 1. - Punched paper tape.

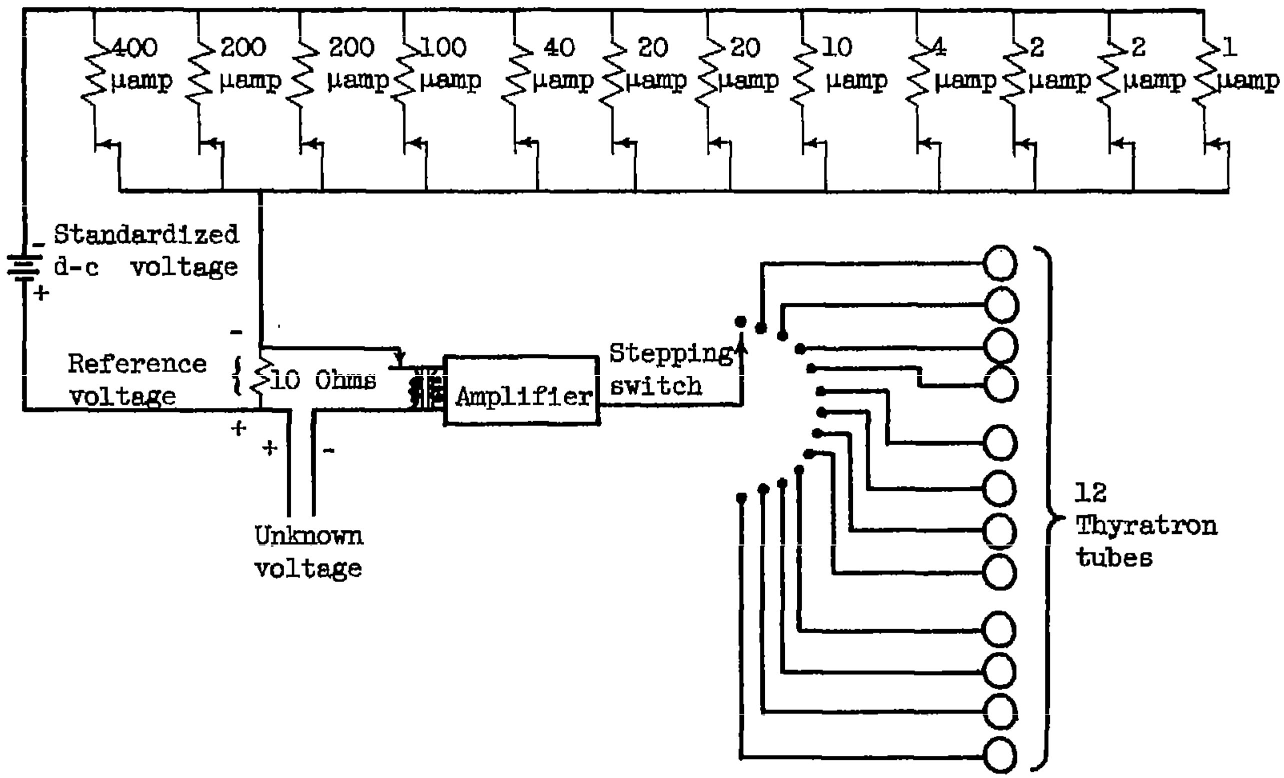


Figure 2. - Potentiometer circuit of type I digitizer.

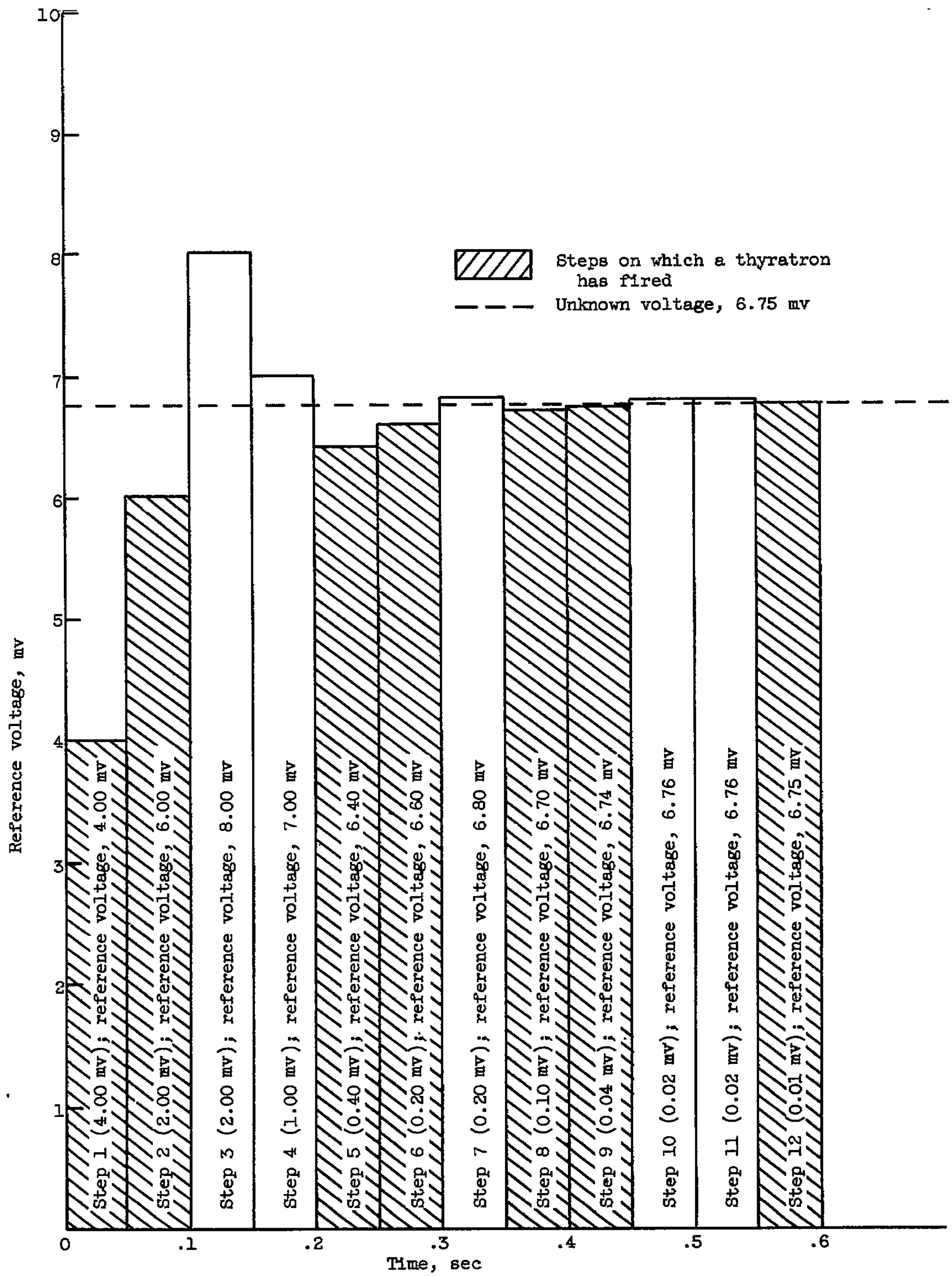


Figure 3. - Reference voltage during balance time of type I digitizer.

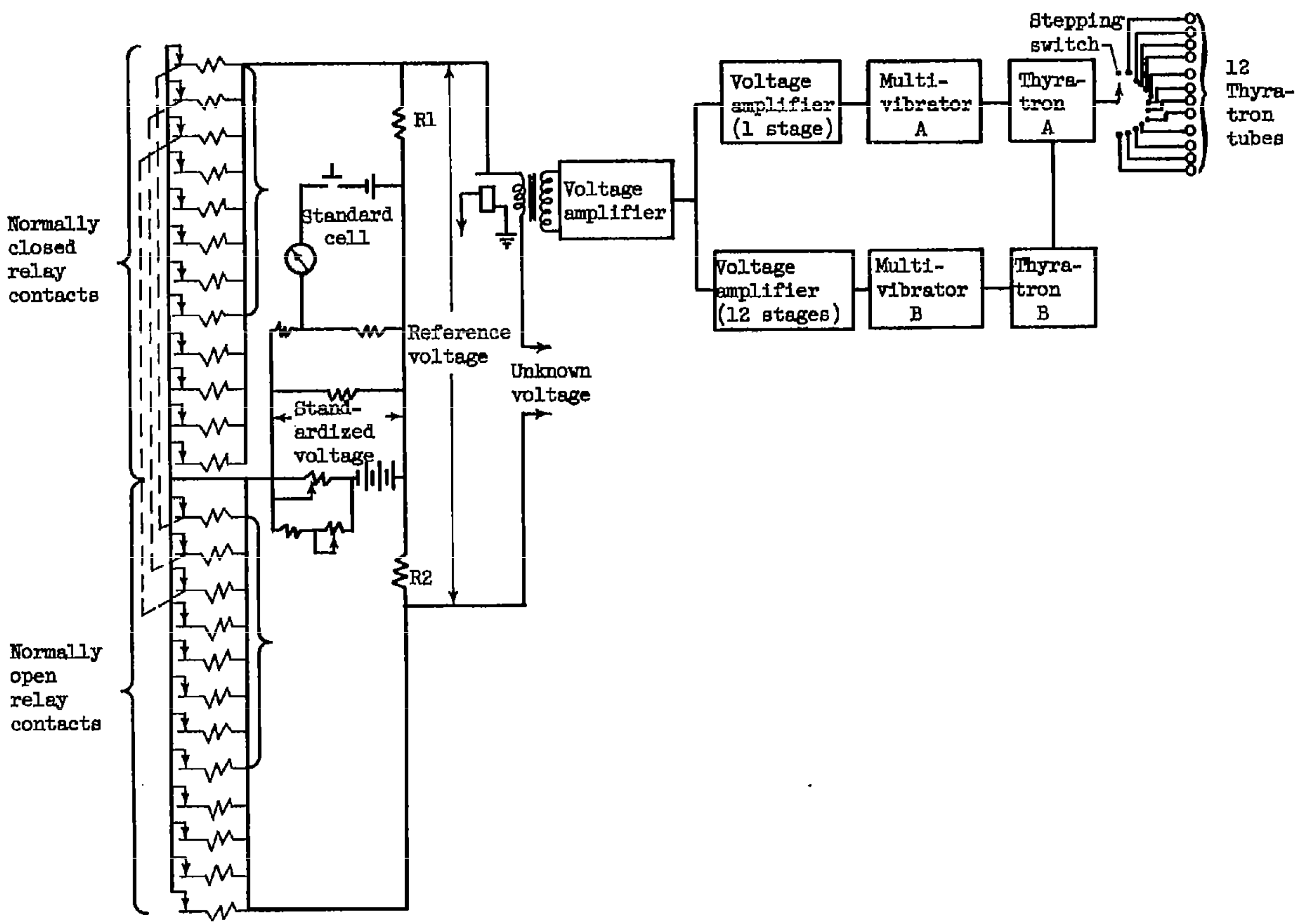
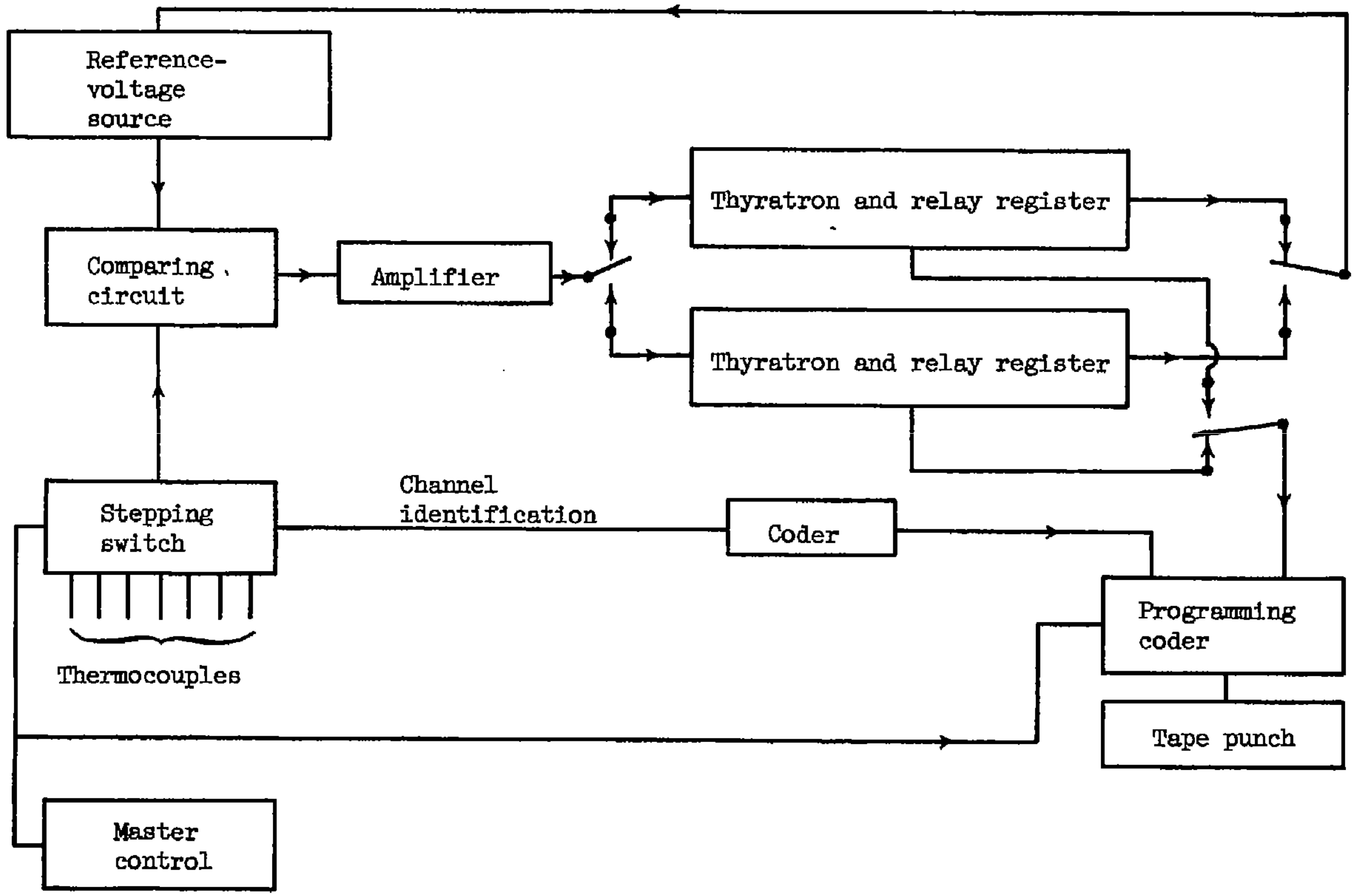
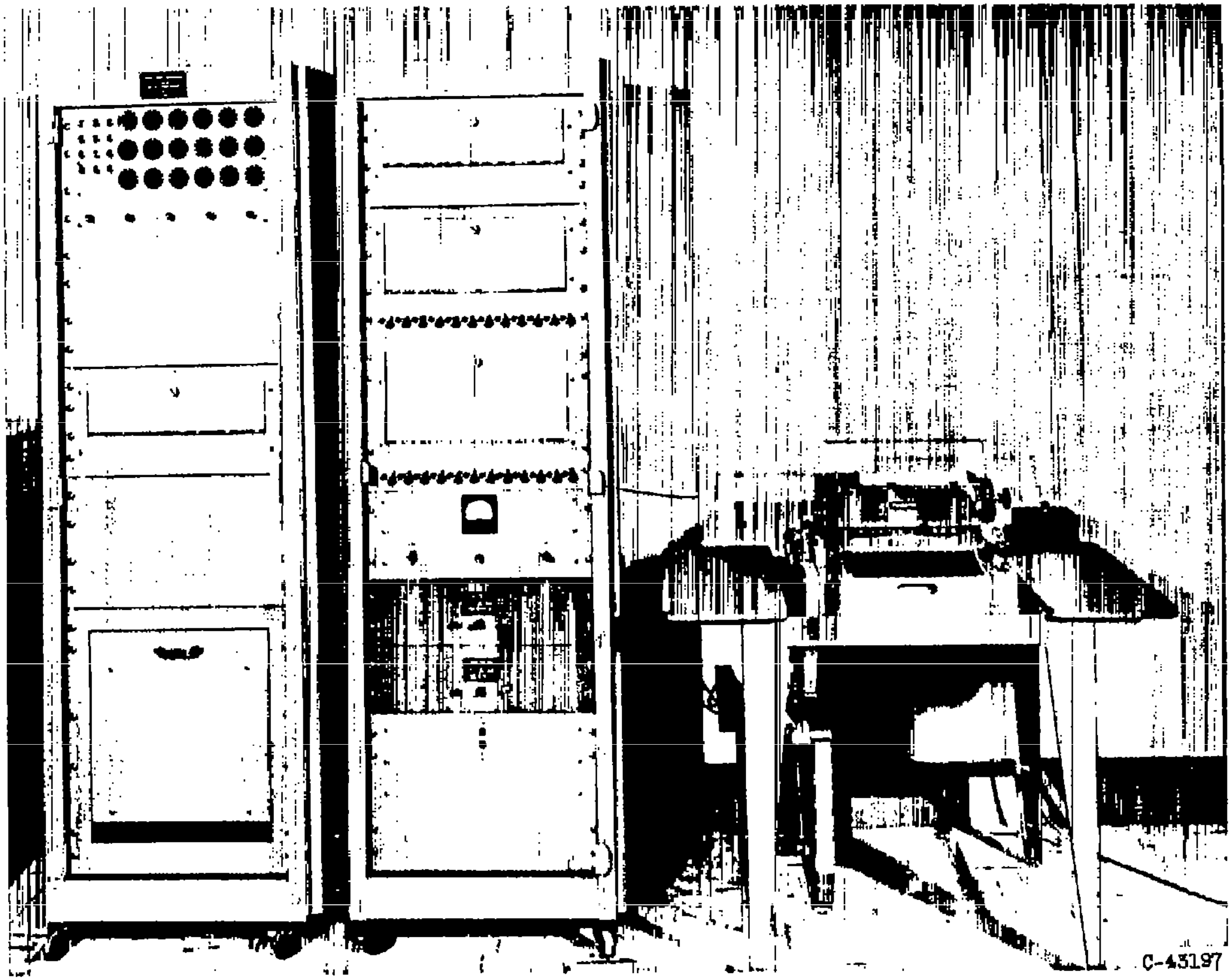


Figure 4. - Detailed circuitry of potentiometer, amplifier, and detector.



(a) Block diagram.

Figure 5. - Type I voltage digitizer.



(b) Photograph.

Figure 5. - Concluded. Type I voltage digitizer.

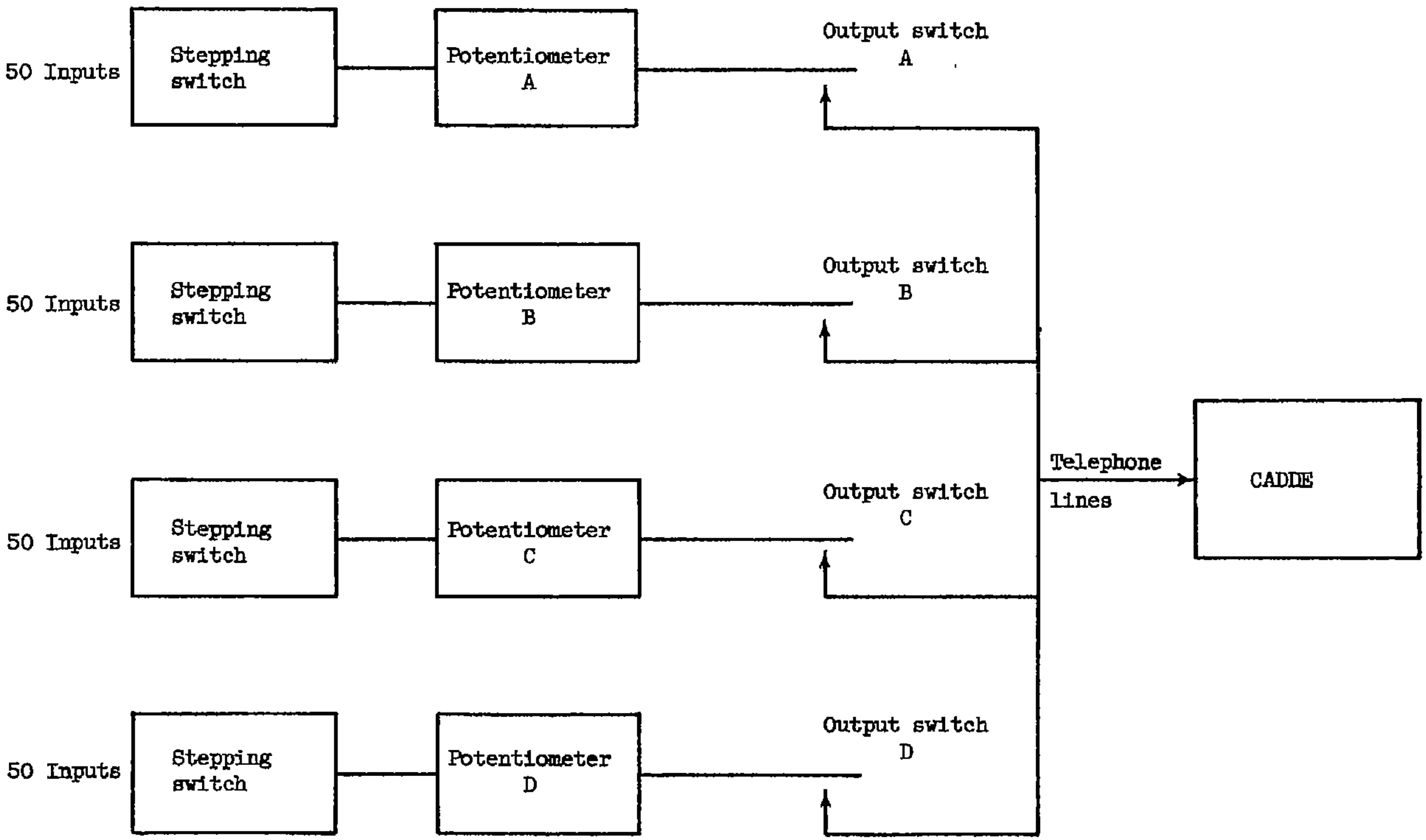


Figure 6. - Block diagram of type II voltage digitizing system.

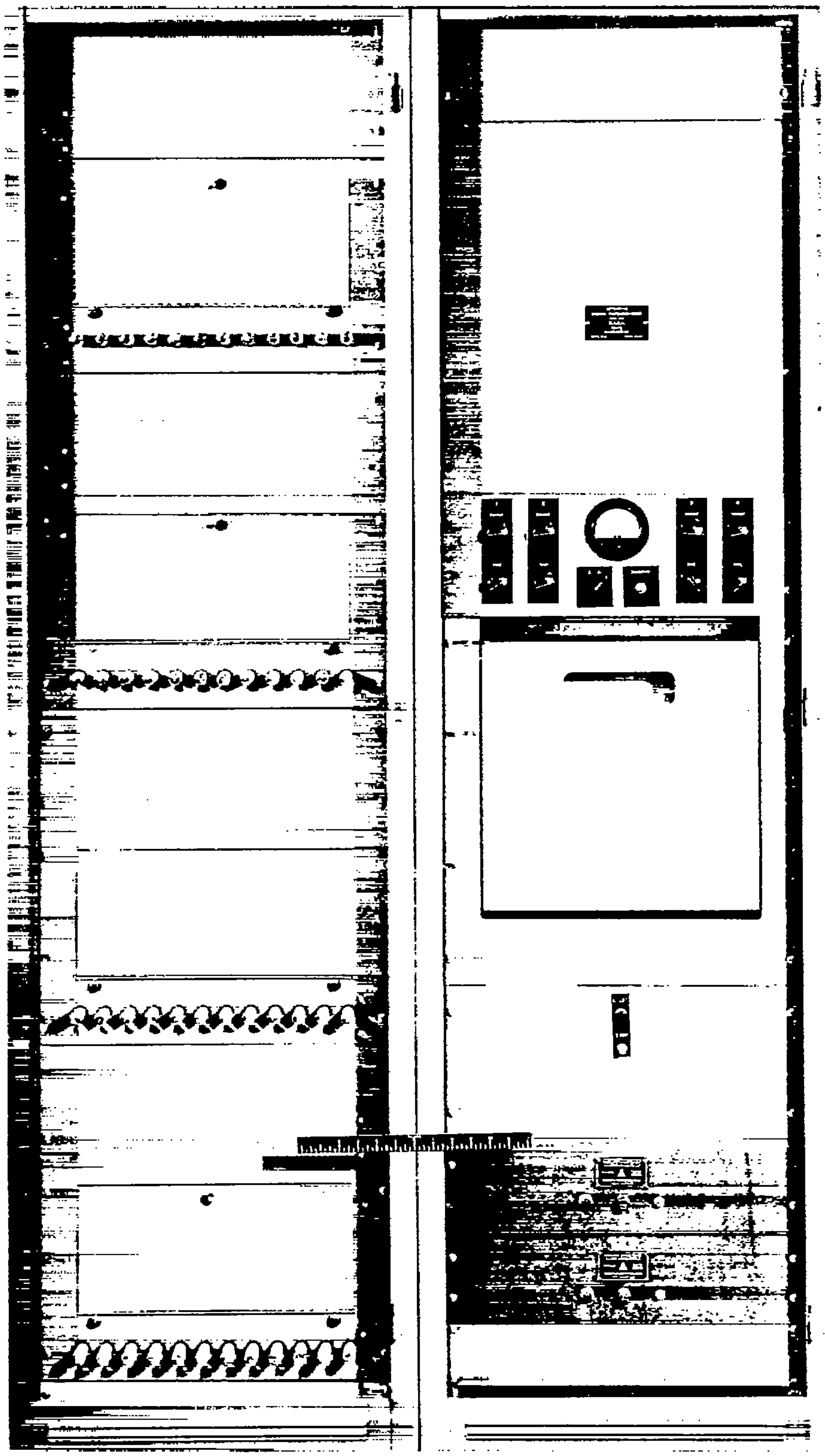


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Figure 7. - Type II voltage digitizer.

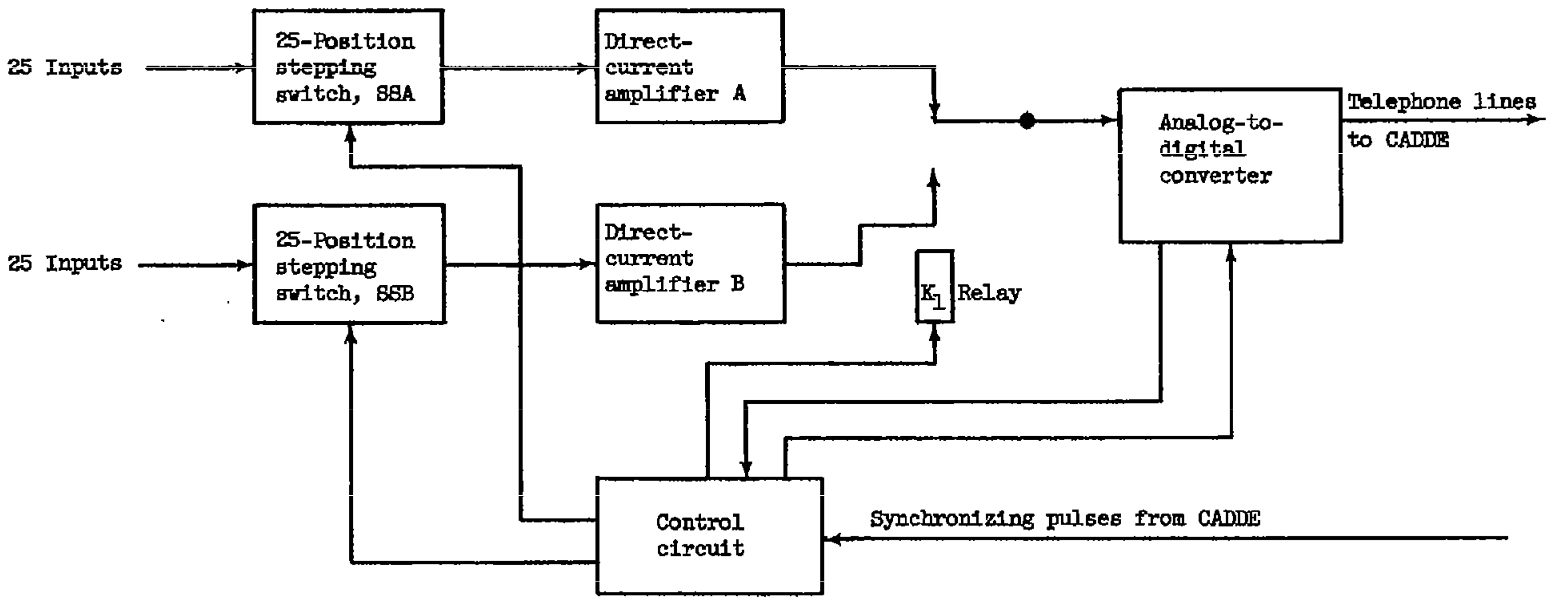

Figure 8. - Block diagram of type III(a) voltage digitizing system.

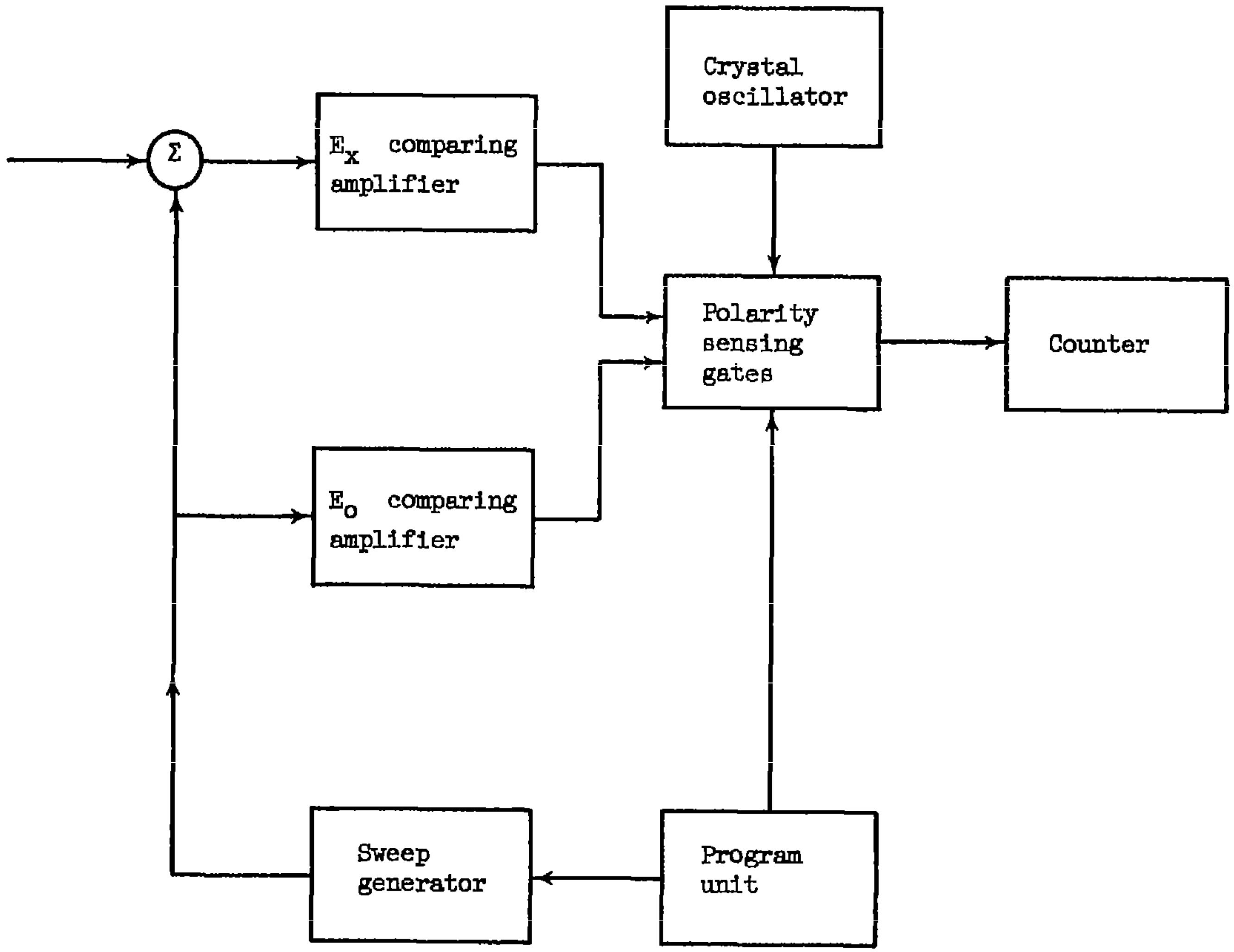

Figure 9. - Block diagram of analog-to-digital converter.

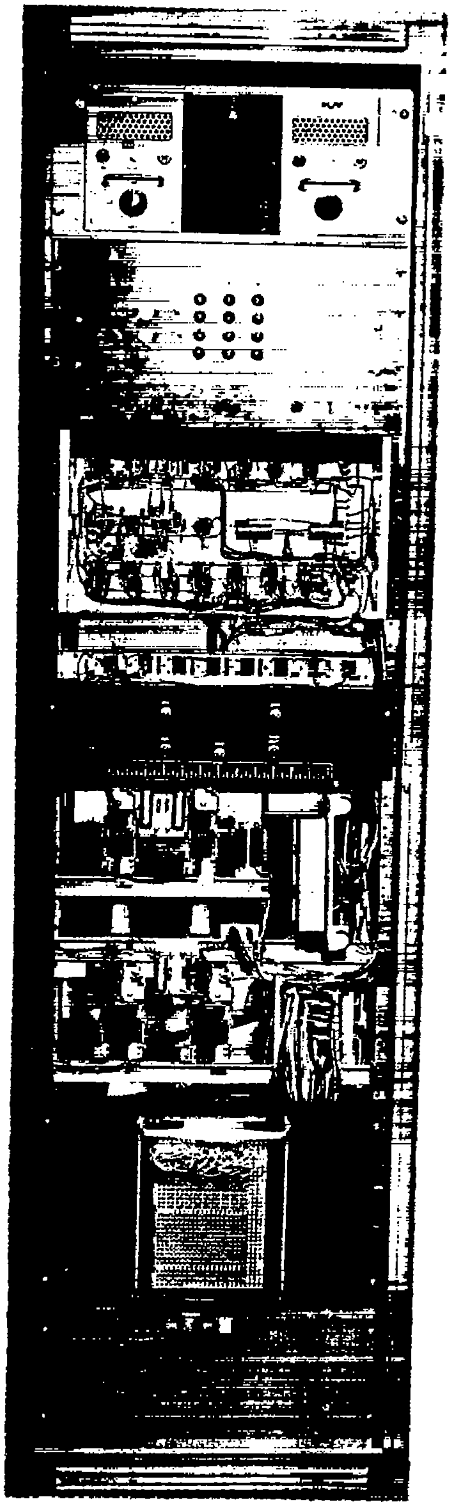

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Figure 10. - Type III(a) voltage digitizer.

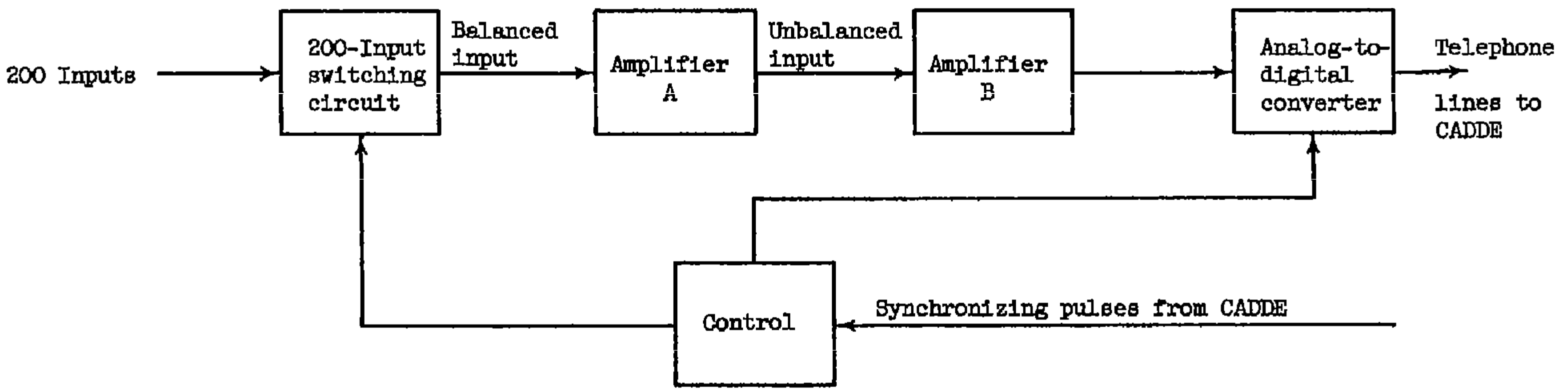

Figure 11. - Block diagram of type III(b) voltage digitizing system.

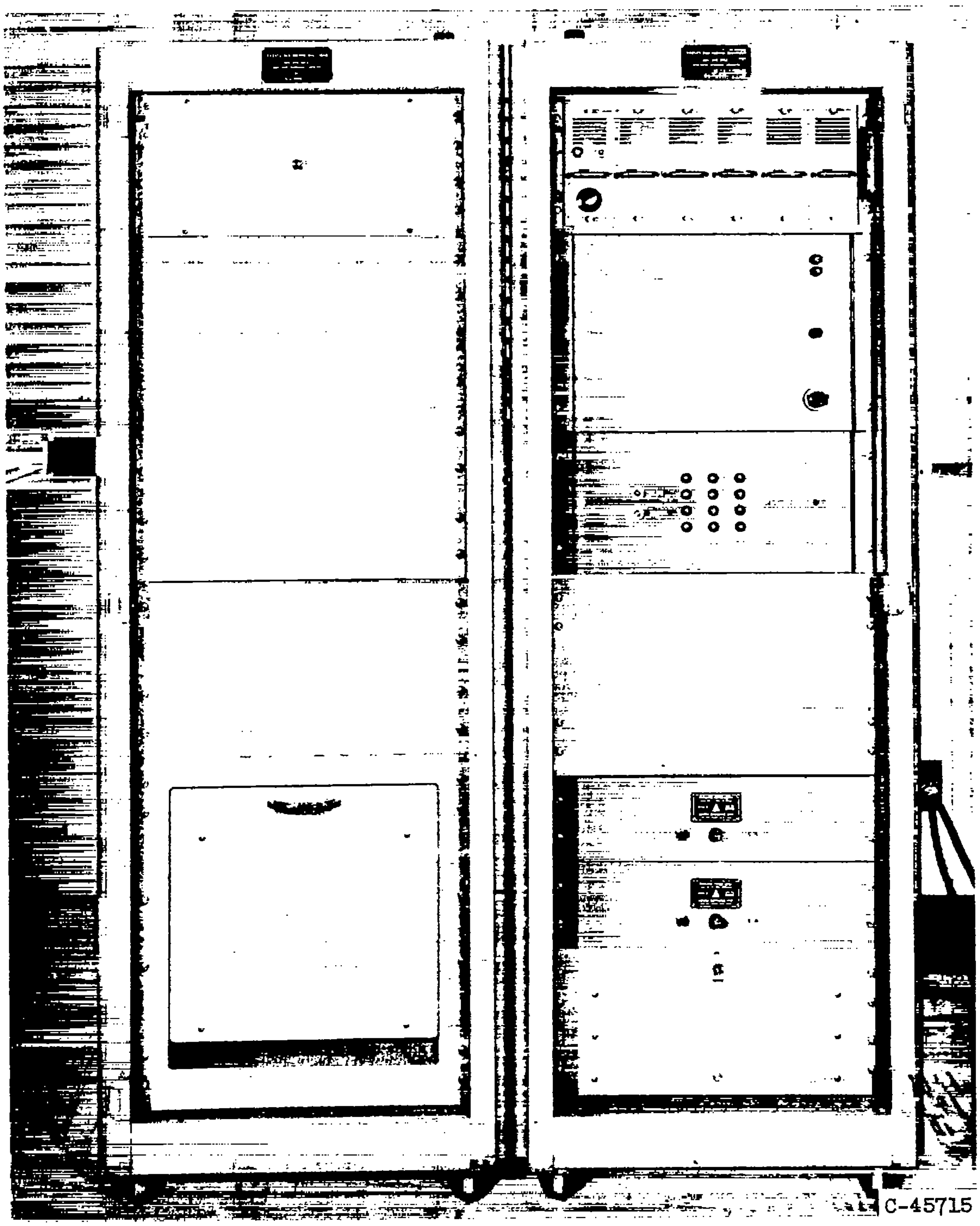

Figure 12. - Type III(b) voltage digitizer.

CHAPTER IV

FREQUENCY DATA

By John Ryskamp

In addition to voltages and pressures, it is also possible for CADDE to record frequency or E.P.U.T. data. In general, any type of device whose output is a voltage having a frequency or repetition rate between 15 and 20,000 cycles per second and an amplitude between 15 millivolts and 50 volts can be used to send data to CADDE for recording.

Two types of frequency data now being handled by CADDE are fuel flow and engine speed. Channel 3 on figure 1 shows the fuel-flow E.P.U.T. equipment. The fuel-flow data are sensed at the remote facility by a turbine-type flowmeter pickup which utilizes a rotating vane propelled by the flowing fuel. Each time a vane passes a magnetic pickup mounted in close proximity, a voltage pulse is generated and, after amplification, is sent to CADDE to be counted. Channel 2 shows the engine-speed E.P.U.T. equipment. Engine-speed data are measured in much the same manner as fuel flow. At the facility a gear driven by the drive shaft of the engine rotates past a magnetic pickup which again generates pulses. These pulses are also sent, after amplification, to CADDE to be counted. As can be seen from figure 1, each E.P.U.T. channel at the field station has its own amplifier in order to provide a signal of constant amplitude and source impedance to the cable carrying the pulses to CADDE. This is necessary since the output voltage amplitude of the frequency devices varies over a large range. As can also be seen from figure 1, each E.P.U.T. channel at CADDE has its own counter and gate. The pulses arriving at the counter of each channel are counted for an accurately measured period of time of 10 seconds or less as determined by the length of time the gates are open. The number representing the time that the gates remain open is stored in the counter of channel 1. In order to convert the number stored in the counter of each other channel to events per second, those numbers are divided by the number appearing in channel 1 which is the time base. The manner in which the time base is generated will be considered before the over-all operation.

In channel 1, a 1-kilocycle crystal-controlled signal is generated at CADDE and is sent to the gate of channel 1 which is controlled by an electronic switching circuit. Depending on its state, this electronic switch, or gate control circuit, allows the gate either to block or pass the 1-kilocycle signal sent to it from the oscillator. When this gate is open, the four-decade counter of channel 1 receives the pulses arriving

at the 1-kilocycle rate and counts them. When 10,000 pulses have been received, a carry pulse out of the final decade is sent to the gate control circuit. The gate control circuit then changes its state, which causes the gate to close. It takes exactly 10 seconds for these 10,000 pulses to be counted, and thus a 10-second time interval is obtained. The number stored in the counter of channel 1, then, is the time base and reads 0000 at the end of the 10-second interval. The control line from the gate control circuit also goes to the gates associated with the other channels (fig. 1). This same control line, therefore, will allow each of these gates to be open for the same time interval the channel 1 gate 4256
is open, which in this case is 10 seconds. The number appearing in the counter of each E.P.U.T. channel, divided by ten, gives events per second.

When the pulse repetition rates from the remote E.P.U.T. equipment are less than 1000 per second, the capacity of the storage counters will not be exceeded during the 10-second time interval. The numbers in the counters will be 9999 or less. This condition holds true, for example, for all fuel-flow measurements.

However, for the engine-speed channels, for example, the pulse repetition rates can vary from a minimum of 500 pulses per second to a maximum of 20 kilocycles as determined by the engine speed and the tachometer that is used. When the pulse recurrence frequency exceeds 1000 per second, the capacity of the four-decade counter will be exceeded in less than 10 seconds. This situation is remedied by adding a fifth decade to the engine-speed channels in order to increase the counter storage capacity. This decade can be inserted electrically by using a relay that is controlled by means of the plugboards associated with each tape handler. Since the data field of the CADDE word has four digits, only the four highest ordered decades are read out onto tape. This solution is satisfactory for pulse repetition rates between 1 and 10 kilocycles.

In a few cases, however, when the pulse repetition rate exceeds 10 kilocycles, even the capacity of the five-decade counter will be exceeded in less than 10 seconds. In this situation the carry pulse emitted by the fifth decade is used to change the state of the gate control circuit to the condition that will close all the gates when the count goes from 99,999 to 100,000. This means that the count in this five-decade channel will read 0000. It also means that the gate controlling channel 1, the time base, will be shut off before the full 10-second time interval is complete. The number in channel 1 will be less than 9999 but will, however, still indicate the time in seconds. As before, the number in each channel, divided by the number in channel 1, gives events per second for each channel.

The over-all operation of recording E.P.U.T. data is as follows: When E.P.U.T. data are to be recorded, they are accumulated at CADDE simultaneously with the measuring of the pressure data. When a call is placed, the gate control circuit is set to the condition which closes all the gates. Immediately after the line switches are closed, the counters are reset to zero. Simultaneously with the start of a pressure scan, the gate control circuit is triggered to the condition which opens all the gates. This allows the counts from the pickups at the facilities and the 1-kilocycle time signal to get to their respective counters and be counted. The first counter reaching its capacity count will emit a carry pulse that will set the gate control circuit to the condition which will close all the gates. If the channel 1 counter emits the carry pulse, its counter will read 0000 and the time interval will have been 10 seconds. If some other channel's counter emits the carry pulse, its counter will read 0000 and the time interval will have been less than 10 seconds, and the number in the counter of channel 1 will be less than 9999. As before, the number in each channel will be divided by the number in channel 1 to obtain events per second.

When the gate control circuit has been closed by a carry pulse, a signal is sent to the central control section of CADDE to indicate that all the E.P.U.T. information is in storage and ready for recording. Upon command from the central control section of CADDE, stepping switches then connect, in turn, the counters of each channel to the recording equipment, and the information is transferred to magnetic tape. This procedure is discussed in greater detail in chapter II.

Up to the present time the CADDE system has provisions for three engine-speed channels and 21 fuel-flow or other frequency channels.

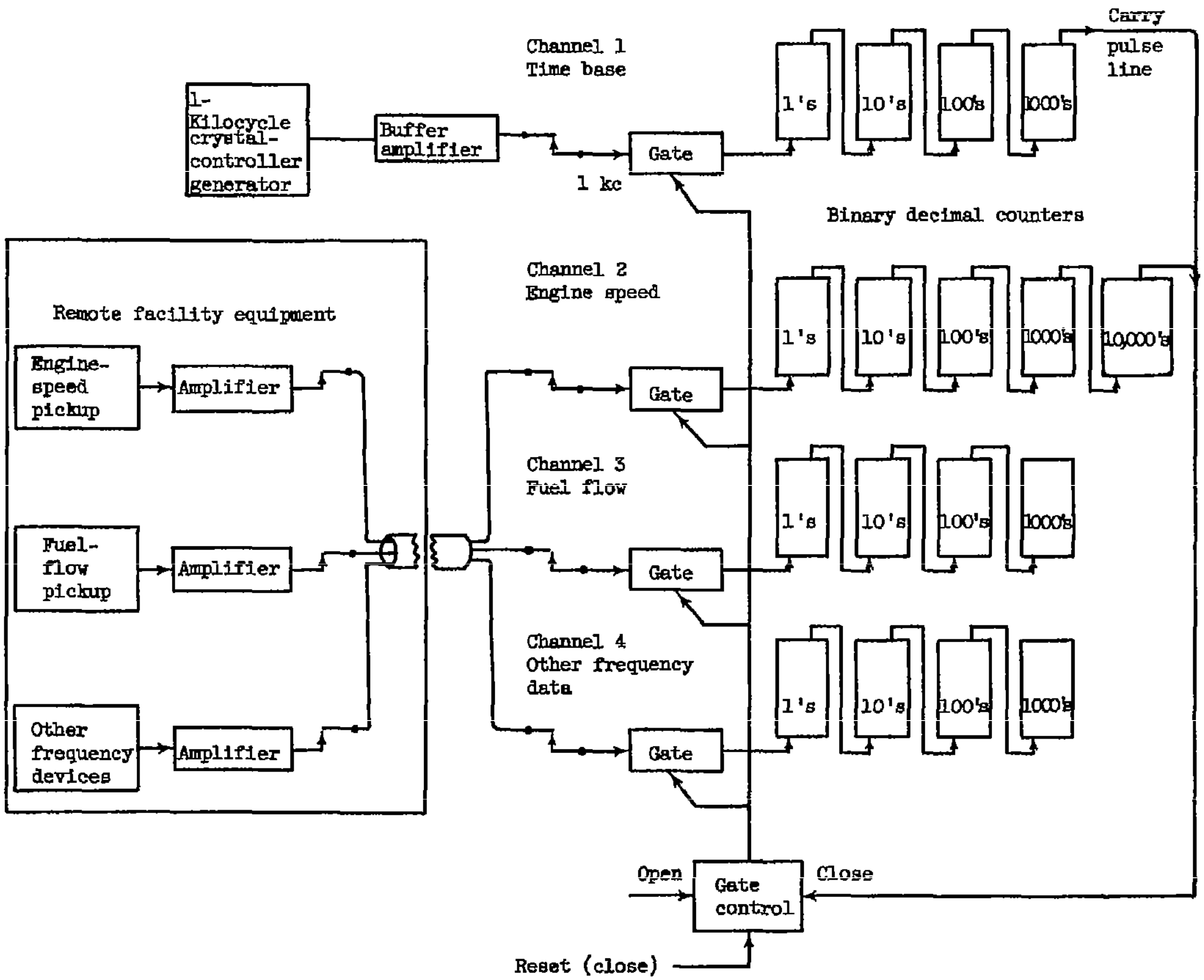

Figure 1. - Block diagram of E.P.U.T. data system.

CHAPTER V

DIGITAL AUTOMATIC MULTIPLE PRESSURE RECORDER

By Leonard Jaffe, Arthur J. Gedeon,
and Richard N. Bell

SYSTEM DESCRIPTION

The Digital Automatic Multiple Pressure Recorder (DAMPR) now in use at this laboratory is a considerably improved version of a system previously described in reference 1. It is a system for measuring and recording in digital form large numbers of steady-state pressures. As many as 300 pressures can be measured, and their values will be temporarily stored in a central memory in 10 seconds. This measurement procedure can be repeated in any given facility as often as every 45 seconds. The central memory disposes of the digital information onto magnetic tapes prepared by CADDE immediately after the 10-second measuring time and can be time-shared by many facilities. Pressures from 50 to 20,000 pounds per square foot absolute can be measured to an accuracy of 0.1 percent of full scale or ± 3 pounds per square foot, whichever is larger.

In this system, pressures are measured by obtaining a time interval proportional to the pressure and counting the pulses of a fixed-frequency oscillator during this time. The number of counts obtained is related to the pressure being measured.

The time interval is obtained by the use of a nearly linear pressure rise generated in the DAMPR scanning tank as shown in figure 1(a). Figure 1(b) shows three differential pressure switches (capsules) mounted on the DAMPR scanning tank with one side of each switch exposed to the tank pressure. These capsules are designed so that an electrical circuit is broken when the pressure on the scanning tank side of the capsule exceeds the pressure applied to the opposite side by a very small amount. Each capsule is electrically connected through telephone lines to a channel of the central magnetic-core memory unit.

When a pressure measurement is to be made, the control unit starts the linear pressure rise and at the same time starts the oscillator feeding pulses to the electronic pulse counter. When the scanning tank pressure exceeds the pressure applied to the opposite side of one of the capsules, the electrical circuit associated with that particular capsule is broken. This break in the circuit tells the memory channel, to which the capsule is connected, to store, or in effect take a picture of, the number of pulses accumulated in the electronic pulse counter at that particular instant. The scanning tank pressure continues to rise until the highest pressure being measured has been exceeded and the time of coincidence of each of the measured pressures with the scanning pressure has been stored in its own channel of the magnetic-core memory.

Figure 1(a) shows that for this example there are stored in the memory a counts low, a counts high, and a counts measured pressure corresponding to the time of coincidence of the scanning pressure with the low reference pressure, the high reference pressure, and the pressure being measured, respectively. For a linear pressure rise, the following calculation produces the value of the pressure being measured P: 4256

$$P = (\text{Counts measured pressure} - \text{Counts low}) \left[\frac{(\text{High reference pressure}) - (\text{Low reference pressure})}{(\text{Counts high} - \text{Counts low})}\right] + \text{Low reference pressure} \tag{1}$$

The high and low reference pressures must be set and maintained constant to the accuracy of the system.

The illustration just given shows only one unknown pressure being measured. In DAMPR installations many capsules are connected to a single scanning tank to measure a number of unknown pressures during the same pressure scan. The magnetic-core memory has the capacity to store 300 pressure readings during one scan.

There are several basic differences between the DAMPR of this report and that of reference 1. First, the use of a nearly linear pressure scan by maintaining sonic flow through an orifice eliminated the need for the costly pressure follower and pulse generator. Second, the concept of a single, central, magnetic-core memory system to serve the DAMPR of all the facilities at this laboratory eliminated the slow, costly, and hard-to-maintain magnetic-drum memory originally used. Third, a much improved capsule of greater reliability and considerably smaller internal volume was developed.

Nonlinearity of Pressure Scan

Since the high pressure supply to the DAMPR scanning tank is not kept absolutely constant (as will be pointed out in the following section) and since the heat-transfer processes occurring during the pressure scan are not completely reversible, the pressure rise is not absolutely linear with time. The deviation from a straight line is less than 0.7 percent of full scale and is reproducible to ±0.05 percent of full scale. This deviation from linearity is taken into account during the reduction of this data.

The constants necessary to describe the deviation from a straight line are stored in a digital computer. The pressure is calculated in the computer as in equation (1). A correction is then calculated by the computer based on the particular pressure and the constants of the correction curve which are stored in the computer. This calculated correction is then added to the result of equation (1) to produce the absolute pressure accurately.

Capsule

A cross section of the NACA-designed pressure capsule used on the scanning tanks is shown in figure 2. The pressure sensitive element is a gold-plated 0.0005-inch beryllium copper diaphragm having an active diameter of 1 inch. Electrical contacts are of gold alloy to ensure a good connection with low contact pressures. The pressure difference required to operate the capsule is less than 0.2 pound per square foot. The volume added to the test pressure system by the capsule is about 0.5 cubic inch including the volume of the capsule fittings.

Each scanning tank has as its source of pressure a supply tank as shown in figure 3. In this tank, sufficient inlet pressure is maintained upstream of the inlet nozzle to the scanning tank to ensure sonic flow through the nozzle during the pressure scan. This ensures a nearly linear pressure rise in the scanning tank. In order to maintain reproducibility of the pressure scan, this supply tank has its pressure reestablished at the end of a scan and controlled at all times except during a pressure scan through the use of a charging system. This charging system is made up of the pressure source, the supply tank, a charging valve, an electronic relay, and a differential pressure switch. This system will control and maintain the supply pressure to within ±1 pound per square inch of the pressure applied to the reference capsule.

The pressure source is kept supplied with air at a pressure of about 270 pounds per square inch, which is sufficiently high to restore the supply tank pressure between scans.

Prior to initiating a scan, the scanning tank must be pumped down to a pressure sufficiently low to ensure that transient conditions have passed and the pressure is rising in a linear manner by the time the lowest pressure to be recorded is reached. An absolute pressure switch connected to the vacuum line is set to close a permissive circuit to a ready light when the tank is pumped down to about 50 pounds per square foot absolute when pressures down to 100 pounds per square foot absolute are to be recorded.

Pump-down time under these conditions is about 45 seconds. If lower pressures are to be recorded, a lower setting is used with a corresponding longer pump-down time.

The scanning tank is a steel tank containing tapped holes to accommodate 160 pressure capsules. Two tanks can be scanned simultaneously, recording up to 300 pressures in a 10-second scanning time. The high and low reference pressures are each connected to five capsules in the top row; the remaining six capsules in this row are used for atmospheric pressures. The other 144 capsules on each scanning tank are available to a facility for recording test pressures. Since all test pressures are computed by interpolating between or extrapolating beyond the counts recorded by the reference-pressure capsules, five capsules are used to record the counts of each of these reference pressures, and the average count is used. By diligently monitoring the counts recorded from these channels, a reference-pressure capsule which begins to deviate from the others can be detected and be "coded out" of the program immediately until it can be conveniently replaced. This action obviates the possibility of computing data based on an erroneous reference-pressure reading.

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The convergent-divergent nozzles used at the inlet of the scanning tank produce a nearly linear and reproducible pressure scan. Nonlinearity of various installations varies between 0.25 and 0.64 percent, but since each tank is individually calibrated periodically and nonlinearity is taken into account as previously discussed, the actual pressure rise is determined to within a maximum probable error of 0.1 percent. A typical correction curve is shown in figure 4. These curves can be closely approximated by segments of two parabolas, and the equations of the parabolas are used to compute the pressure correction. This correction is added algebraically to the pressure as computed by equation (1).

The supply pressure and the area at the throat of the nozzle determine the rate of pressure rise in the scanning tank and, therefore, the span of pressures measured in a scanning cycle. Spans for DAMPR have been standardized at 2,000, 5,000, 12,500, and 20,000 pounds per square foot. Nozzles for all spans are interchangeable to meet changing requirements on the system.

CONTROL SYSTEM

The DAMPR control equipment shown in figure 3 provides proper sequencing of the DAMPR pneumatic system and connects the capsules to telephone lines for data transmission to CADDE.

Figure 5 shows the DAMPR pneumatic cycle. Data are taken during the scan portion of the cycle, and the pressure capsules are connected to CADDE only during this time. During any standby periods the scanning tank remains connected to the vacuum pump.

The three valves shown in figure 3 control the steps of the pneumatic cycle. The "vacuum exhaust" valve connects the scanning tank to the vacuum pump for exhausting to a vacuum. The "pressure in" valve admits air under pressure from the supply tank, and the "atmospheric exhaust" valve opens the scanning tank to the atmosphere.

Automatic operation of the valves in the proper sequence is provided by the control equipment (fig. 3). The control system was designed for reliable and fail-safe operation. Interlock circuitry prevents operation unless all the DAMPR components are ready and CADDE is prepared to accept the data to be taken. The valves which control the steps of the operating cycle are arranged so that the scanning tank is opened to the atmosphere whenever the power is off. A trouble relay in the control equipment may be operated by CADDE to lock the DAMPR system and prevent operation if a failure or malfunction occurs. The release button on the control panel permits the operator to interrupt the cycle at any point, and the system will automatically return to standby condition.

Connections to CADDE are provided by telephone lines which are divided into two groups. One group is used to transmit control information between DAMPR and CADDE. This control signal information operates lights on the control panels to inform the operators of the status of DAMPR and CADDE. Approximately 12 permanently connected lines are used to transmit this information. The other group of telephone lines, used for data transmission, individually connects each capsule to a channel of the magnetic-core memory at CADDE. The 300 telephone lines in this group are connected to the capsules only when pressures are to be recorded. Line switches in the DAMPR control equipment can be operated by CADDE to connect the lines when required. A patch board permits any pressure capsule to be connected to any one of the 300 data transmission lines and consequently to any channel of the magnetic-core memory.

The DAMPR equipment may be operated from either the cabinet containing the control equipment or from the facility control room where remote lights and switches are installed. In order to operate the DAMPR system the power switches are first turned on. The vacuum pump exhausts the scanning tank to a vacuum, and the supply tank fills with compressed air from the compressor supply tank. When all necessary conditions are reached and the interlocks are set, a ready light indicates that the DAMPR system is prepared to measure pressures. The operator may then place a call to CADDE by pressing a button on the control panel. When CADDE is ready to accept data, a signal sent back to the DAMPR installation connects the capsules to the telephone lines.

The operator may then press a button to start the scanning portion of the cycle. Several things then happen simultaneously. The "vacuum exhaust" valve closes, and the "pressure in" valve opens to admit compressed air from the supply tank. This causes the count starting pressure switch to operate and send a signal to CADDE which starts the count generator. The DAMPR system then continues automatically through the pneumatic cycle.

The high limit pressure switch operates at the end of the scanning portion of the cycle. This closes the "pressure in" valve and opens the "atmospheric exhaust" valve. A signal sent to CADDE stops the count generator, and CADDE then disconnects the capsules from the telephone lines. The scanning tank exhausts to the atmosphere until it reaches a pressure of approximately 2 pounds above atmospheric. At this point the "atmospheric exhaust" valve closes, and the "vacuum exhaust" valve opens. The scanning tank is reevacuated, and the supply tank is refilled. As soon as all necessary conditions are reached and the interlocks are set, a ready light indicates that the DAMPR system is again ready to measure pressures.

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The accuracy of pressures computed from DAMPR data depends upon the accuracy with which the reference pressures are set and maintained. Means are provided to set these required pressures easily and accurately.

A low reference pressure of 141 pounds per square foot absolute for all ranges has been established. It is indicated by an aneroid-type absolute pressure gage having a range of 0 to 150 pounds per square foot absolute.

The high-reference-pressure capsules on a scanning tank are connected to one of four available reference pressures. The high reference pressure may be 2,141, 5,141, 12,641, or 20,141 pounds per square foot absolute as may be required for any given program and is indicated on gages having an accuracy of 1/1000 of full scale. The gages are custom-calibrated, and the scales are hand drawn to match the calibration. Temperature corrections are negligible within the usual range of room temperature.

Figure 6 is a photograph of a DAMPR installation showing the control cabinet, reference-pressure gage panel, and scanning tanks.

MAINTENANCE

At least three capsule checks are made daily for each scanning tank currently in use. A capsule check consists of a pressure scan with all capsules vented to atmospheric pressure. Any capsule whose count varies from the average count by more than a given tolerance is adjusted or replaced immediately. Tolerances vary from ±2 counts to ±4 counts, depending upon the range used. Usually only one or two capsules on each tank require adjustment. Occasionally, and in some cases daily, similar checks are made at altitude conditions by operating personnel. All reference gages are field checked monthly by comparing them with secondary standard gages at the pressures at which they are used. Any scale correction is noted on the front of the gage.

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Calibration checks are made at the beginning of each new program and at about 6-week intervals for extended programs. Accurately measured pressures are applied to a group of ten capsules, and the DAMPR tank is scanned. This is repeated for at least 20 increments of pressure varied over the full range of pressures. By assuming a linear pressure rise values of pressure are computed from the recorded counts and are compared with the true applied pressure. The observed pressure differences are used to prepare a correction curve. Variation among successive calibrations on the same scanning tank has been minor.

MEMORY SYSTEM

Since the coincidence of the scanning pressure with each of the measured pressures may occur at random times, it is necessary to store the information temporarily in a memory system. This memory must be capable of accepting information into its various channels at random times and also must be capable of being "read out of" in some logical order. To serve this purpose a magnetic-core memory has been used.

The basic element of this memory is a magnetic core of molybdenum permalloy which has a rather rectangular hysteresis loop as shown in figure 7. This hysteresis loop shows that, if the core is subjected to a sufficient number of ampere turns ($+I_s$ or $-I_s$) in order to saturate it, after the magnetizing force is removed the core will remain in either one of two remanent flux densities ($+B_r$ or $-B_r$). A value of "1" is assigned to the $+B_r$ state, and a value of "0" is assigned to the $-B_r$ state. Figure 7 also shows that a magnetizing force of $+\frac{1}{2} I_s$ or $-\frac{1}{2} I_s$ will not effect a change in the state of the core.

Figure 8 is a block diagram of the coincident-current magnetic-core memory used in the DAMPR system. Sixteen cores in a vertical column constitute one channel of information capable of storing a four-digit number. Associated with each vertical column or channel is a gate capable of sending a $\frac{1}{2} I_s$ current pulse through its 16 cores. Each gate, in turn, is controlled by a capsule at the pressure measuring station. Through each of the 16 horizontal rows are wires connected to the 16 corresponding binary stages of a four-decade electronic counter. Should a binary stage of the counter contain a "1", a $\frac{1}{2} I_s$ current pulse is passed through the horizontal row of 300 cores with which it is associated. A binary stage containing a "0" passes no current through its associated wire.

When a scan at a DAMPR station begins, the 1-kilocycle oscillator is started. The output of the oscillator and pulse shaper feeds pulses to the electronic counter and to each of the 300 capsule gates. When a capsule opens, indicating coincidence of pressures, an electrical signal is sent to its corresponding capsule gate in the core memory, and, when the next oscillator pulse is delivered, the capsule gate will send one, and only one, $\frac{1}{2}\ I_s$ current pulse to the 16 cores of its particular channel. Coincidently, current pulses of $\frac{1}{2}\ I_s$ are sent over the horizontal wires in a pattern determined by the number existing in the electronic counter at that instant. The cores in this channel which receive coincident $\frac{1}{2}\ I_s$ current pulses will change their magnetic state from a "0" to a "1". Cores not receiving coincident pulses will remain in the "0" state. Thus, the number which existed in the electronic counter has been stored in the cores of this particular channel.

After all capsules have operated and the memory is full, a read-out cycle is commanded automatically by the DAMPR station.

Read out is accomplished by sending a current pulse of $-I_s$ or greater through one vertical column or channel at a time and sensing any voltage change due to a changing flux by a third wire in each horizontal row. The read-out rate is 20 channels per second and is controlled by a stepping switch. When read out is complete, the memory is automatically reset and is ready to accept another block of data.

Figure 9 shows a single-bobbin-type molybdenum permalloy core, and figure 10 presents a 16-by-10 matrix of cores already mounted and wired. This matrix comprises ten channels of memory. It takes 30 such boards to make up the complete 300-channel memory.

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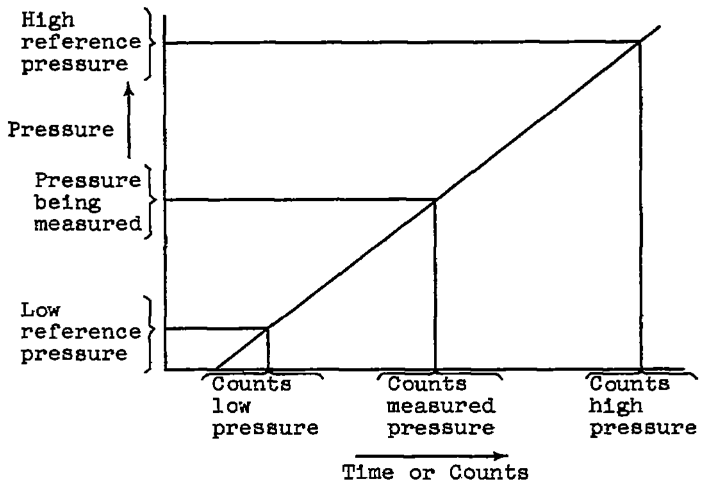
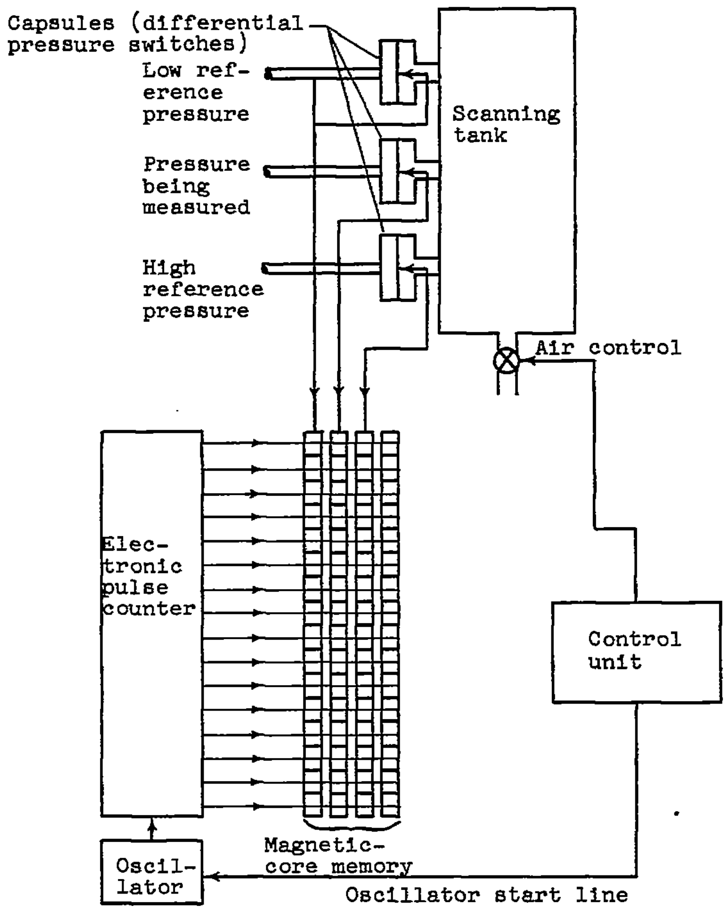


(a) Pressure rise.



(b) Schematic diagram of pressure measuring system.

Figure 1. - DAMPR pressure measuring system.

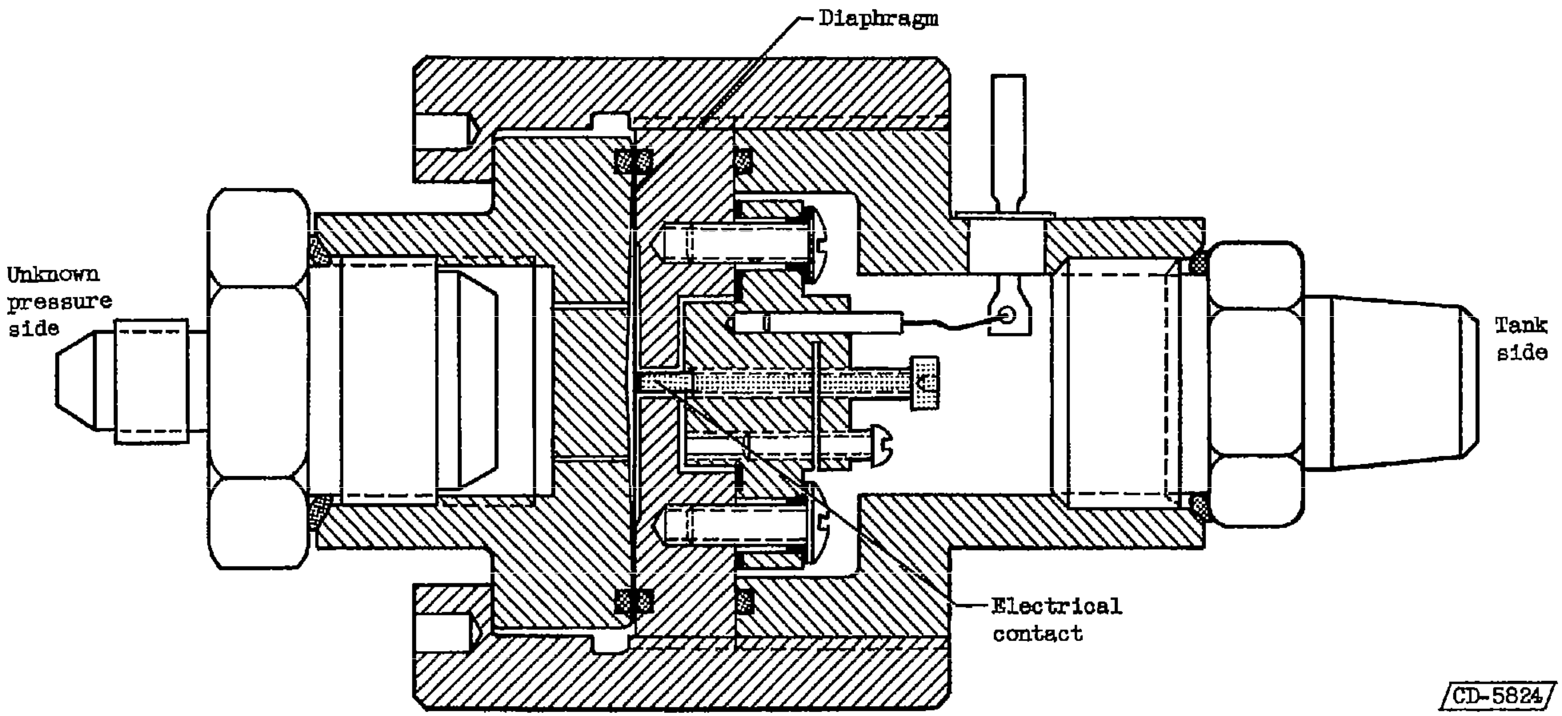


Figure 2. - DAMPR pressure capsule (approx. twice regular size).

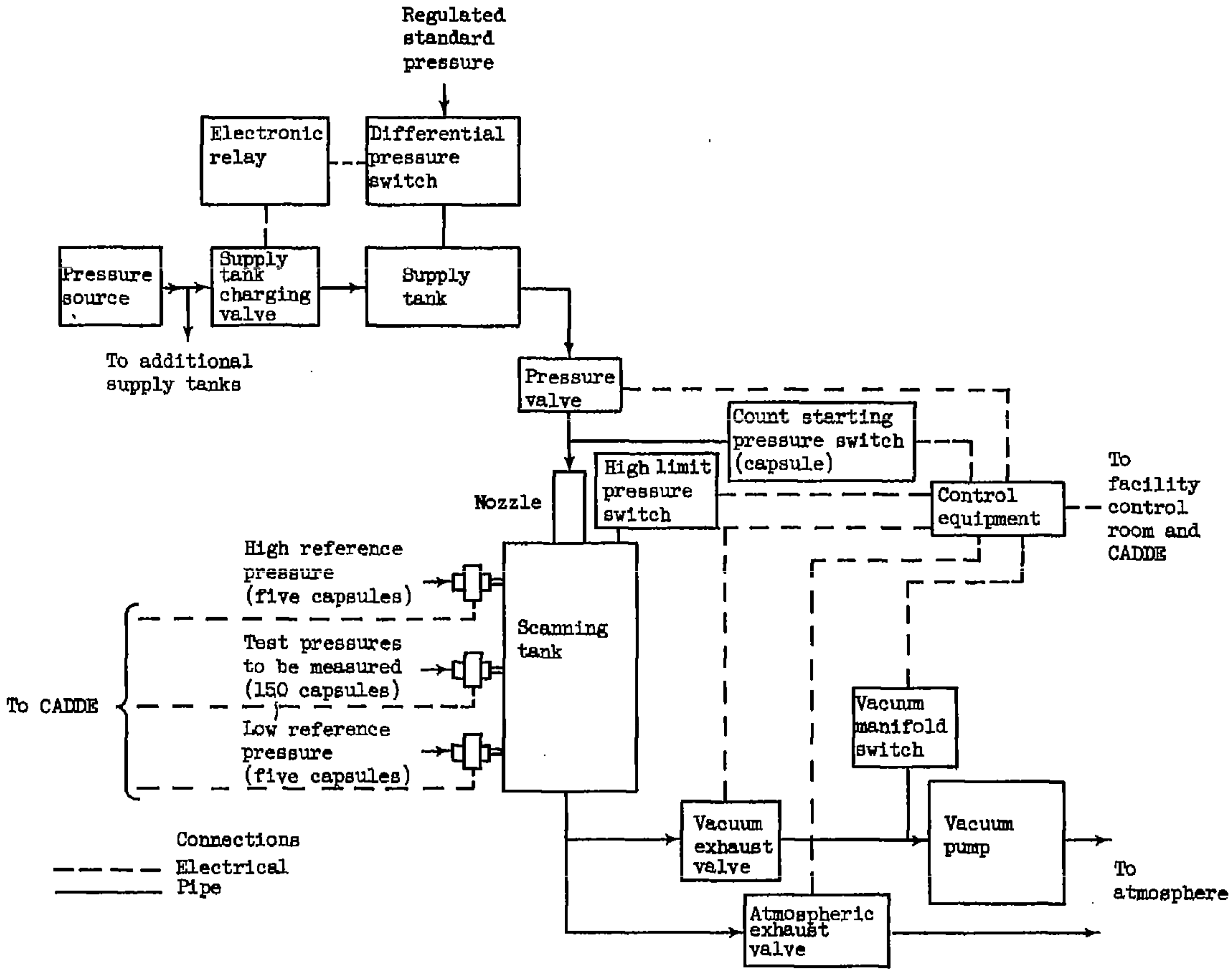


Figure 3. - Schematic DAMPR field station.

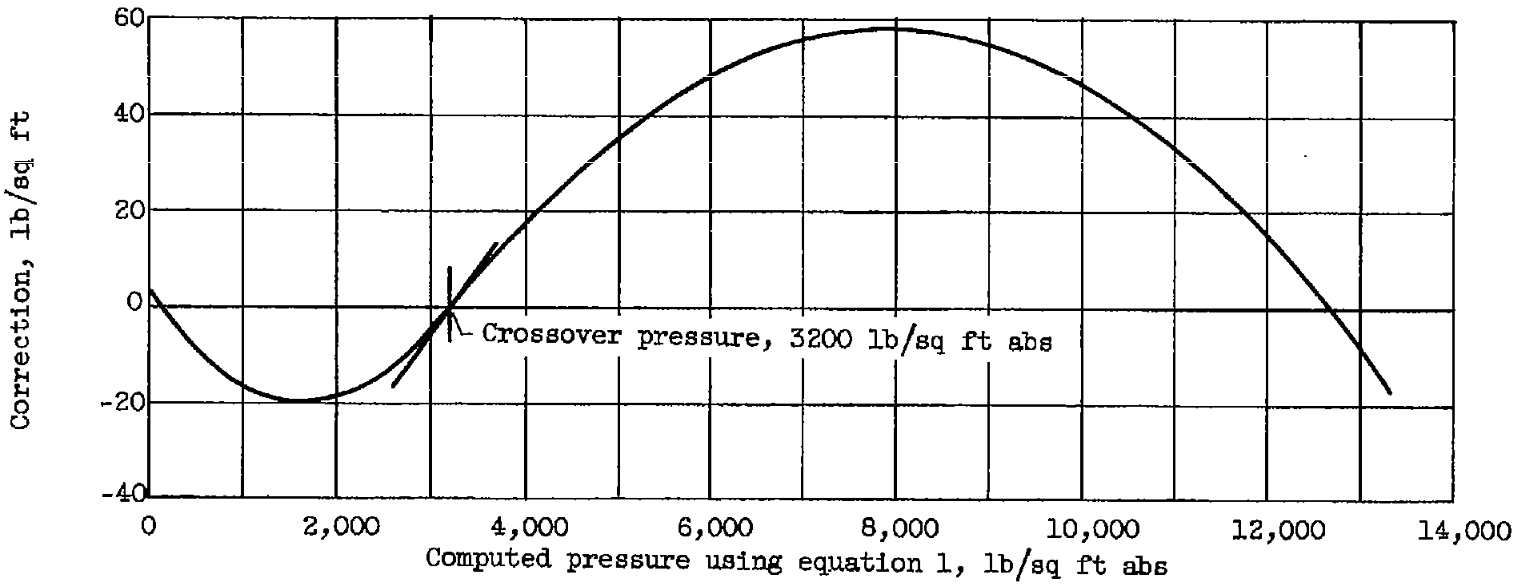


Figure 4. - Typical DAMPR correction curve. Low reference pressure, 141 pounds per square foot absolute; high reference pressure, 12,641 pounds per square foot absolute; crossover pressure, 3200 pounds per foot absolute; supply pressure, 200 pounds per square inch gage; nozzle diameter, 0.121 inch.

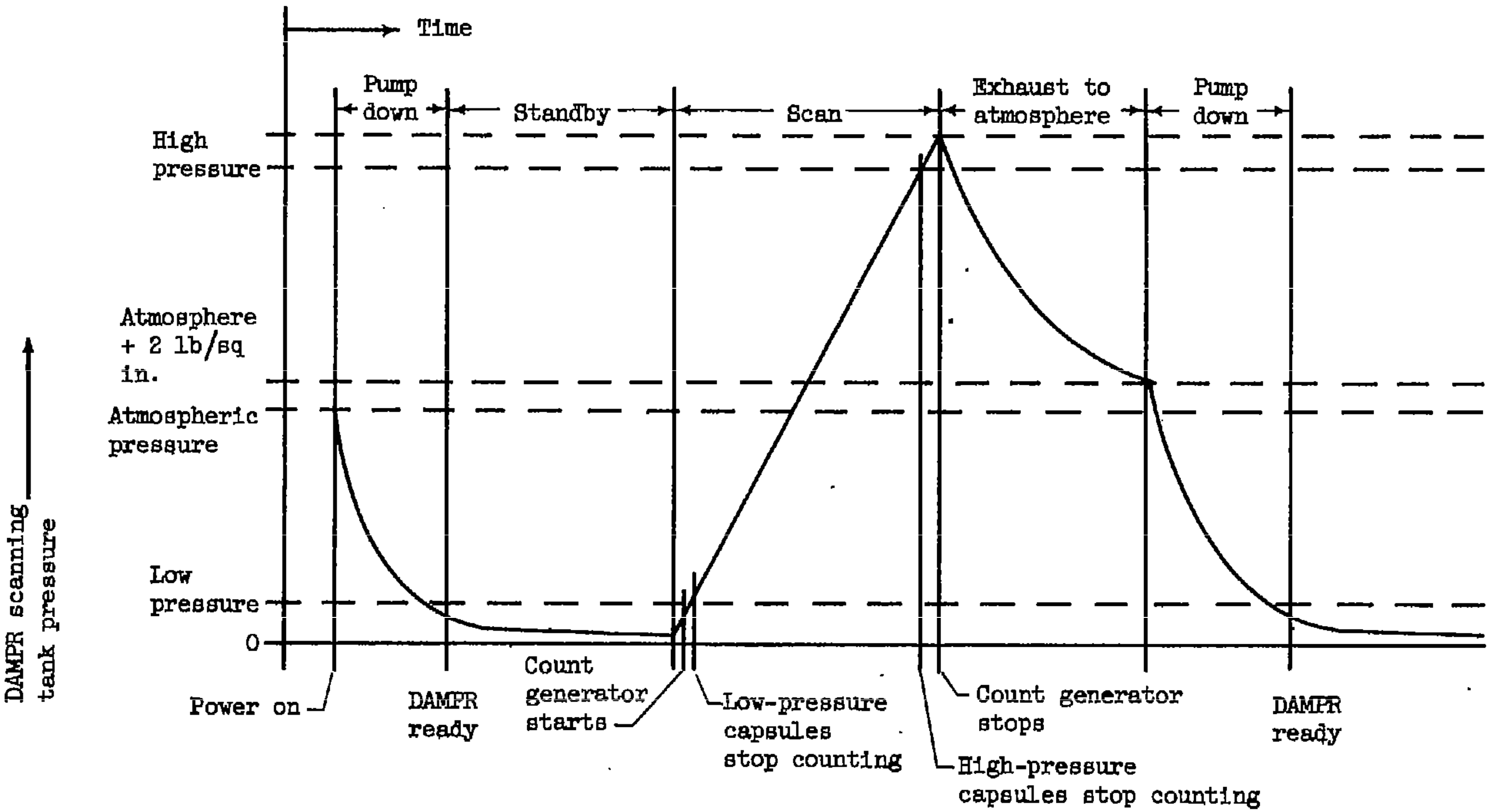


Figure 5. - DAMPR pneumatic cycle.

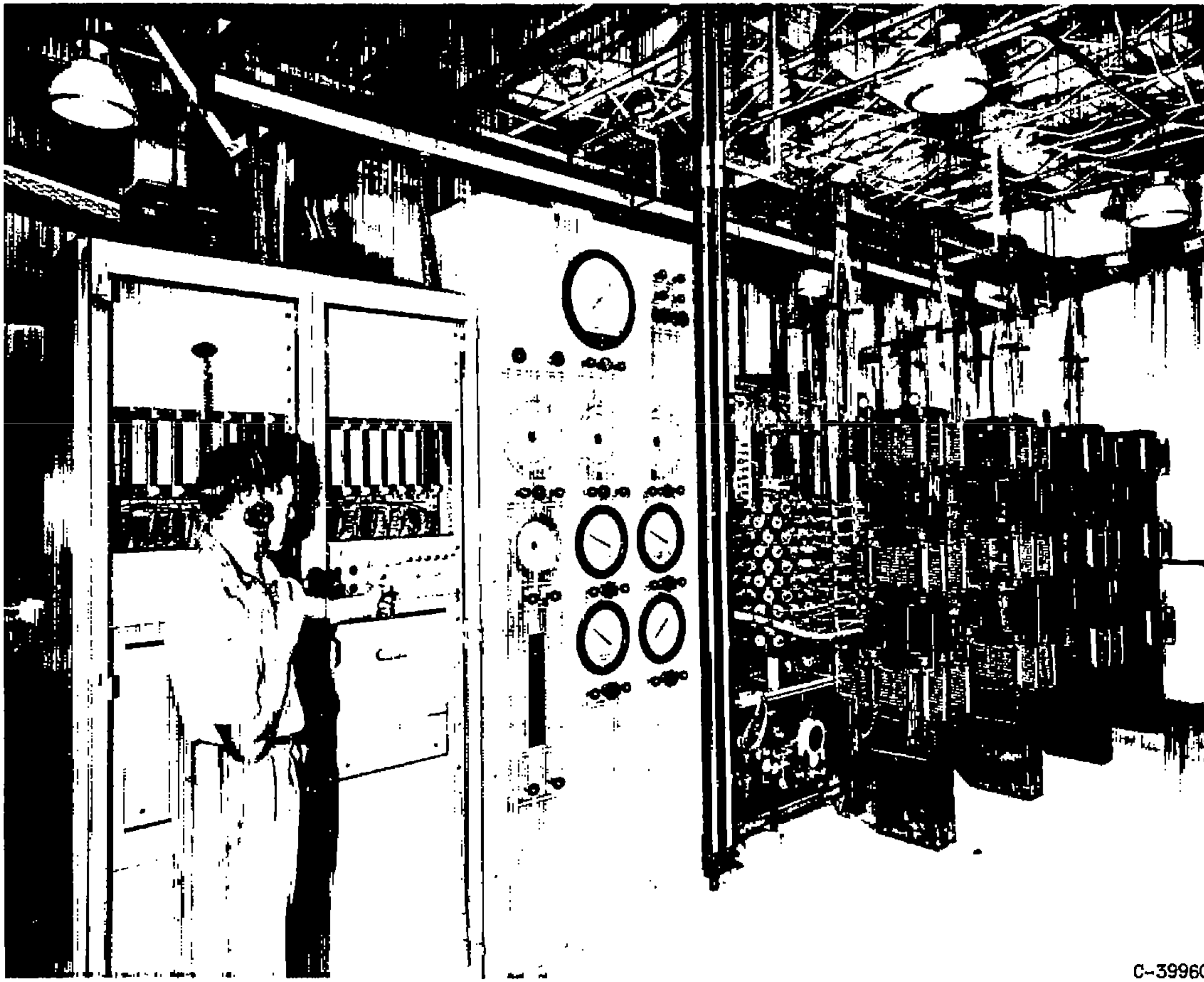


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Figure 6. - DAMPR installation.

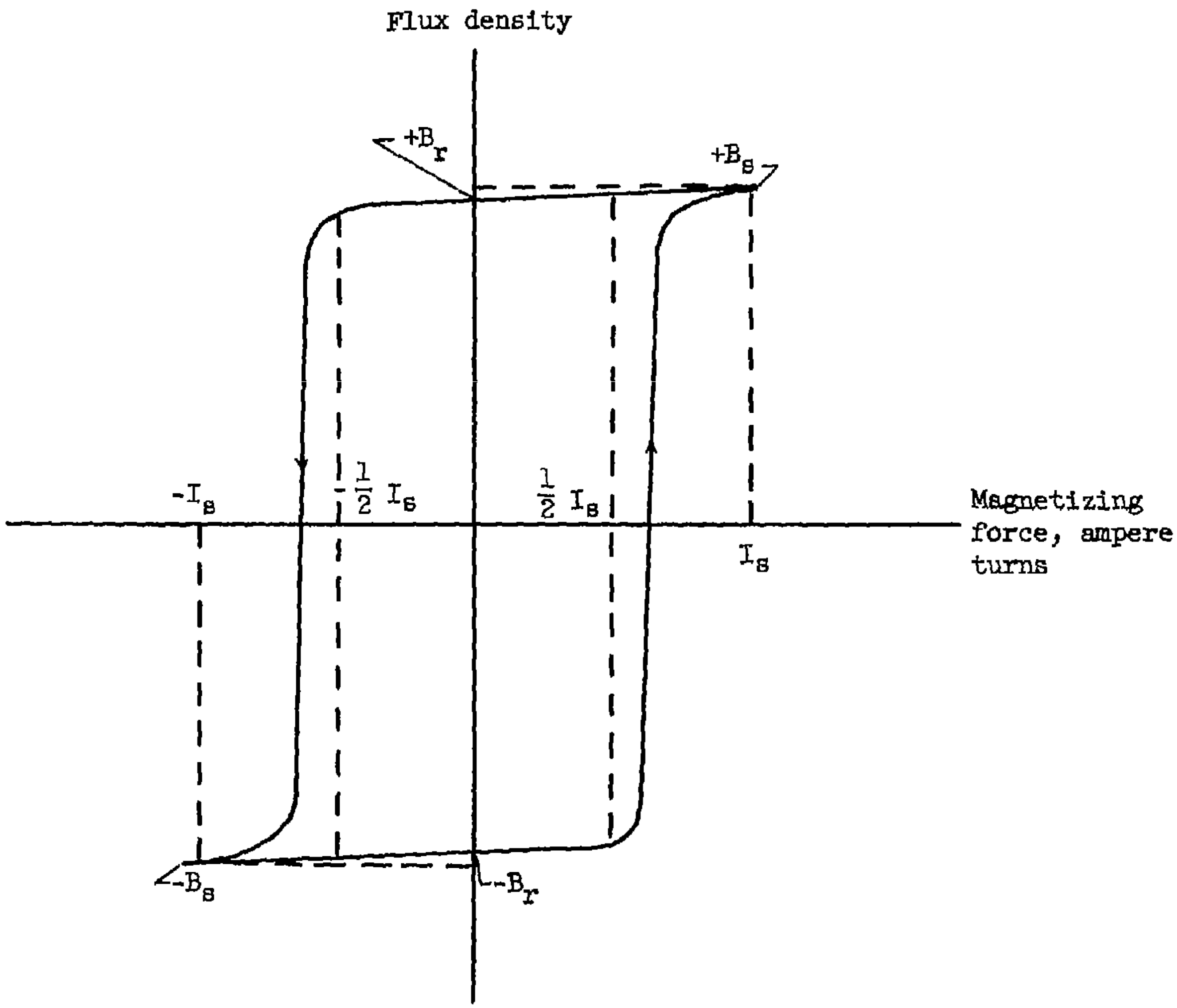

Figure 7. - Magnetic-core hysteresis loop.

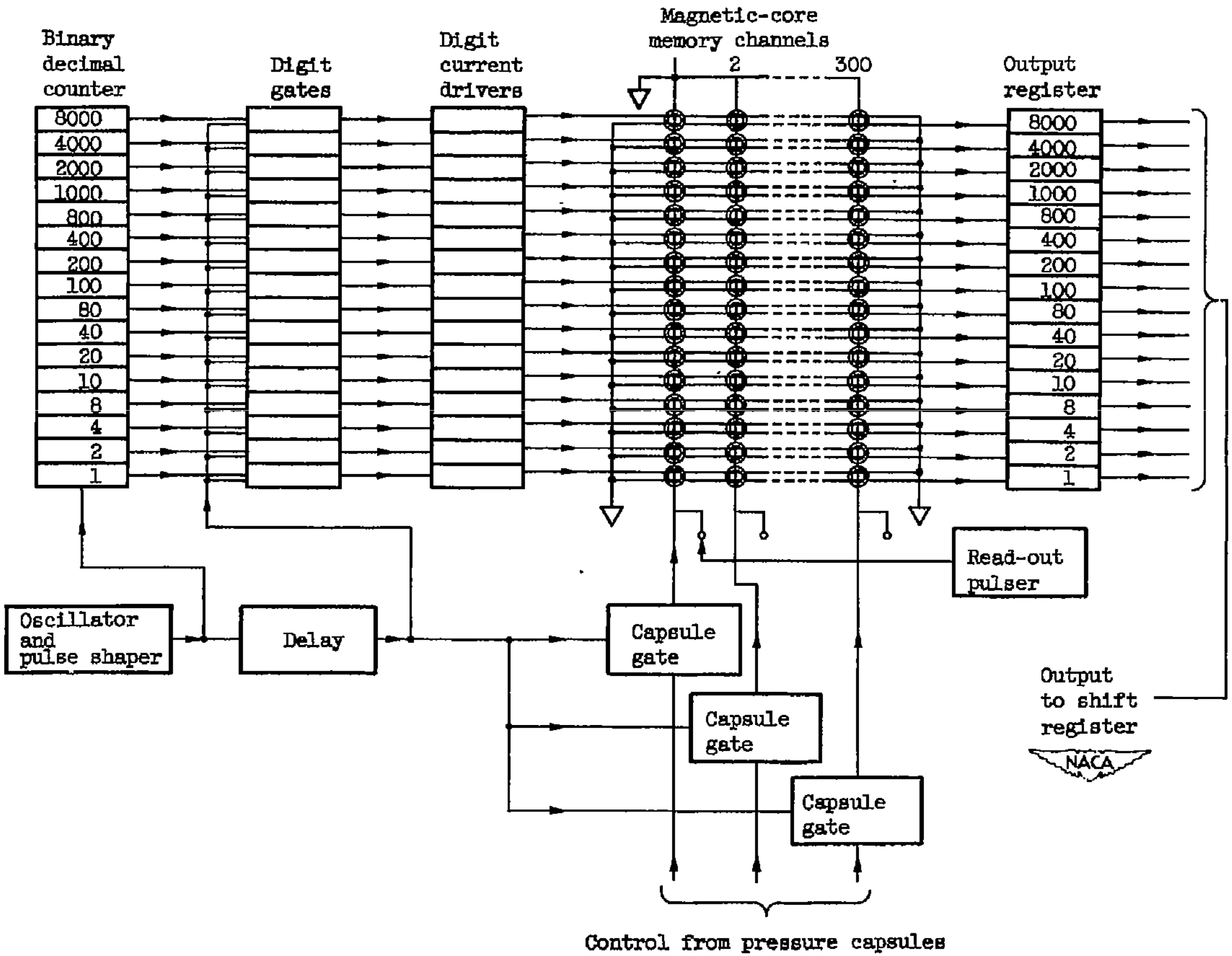

Figure 8. - Magnetic-core memory.

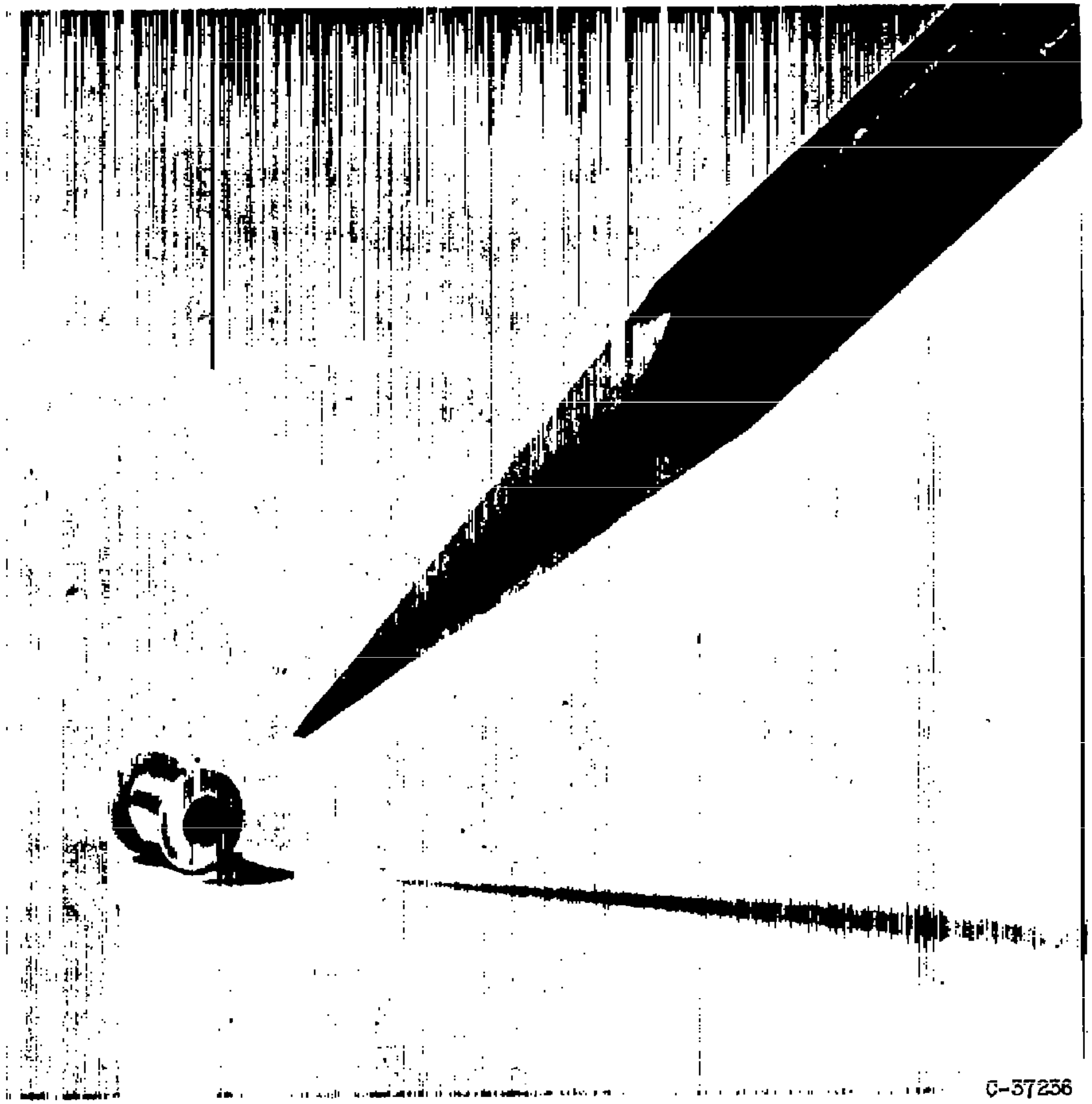

Figure 9. - Magnetic memory core.

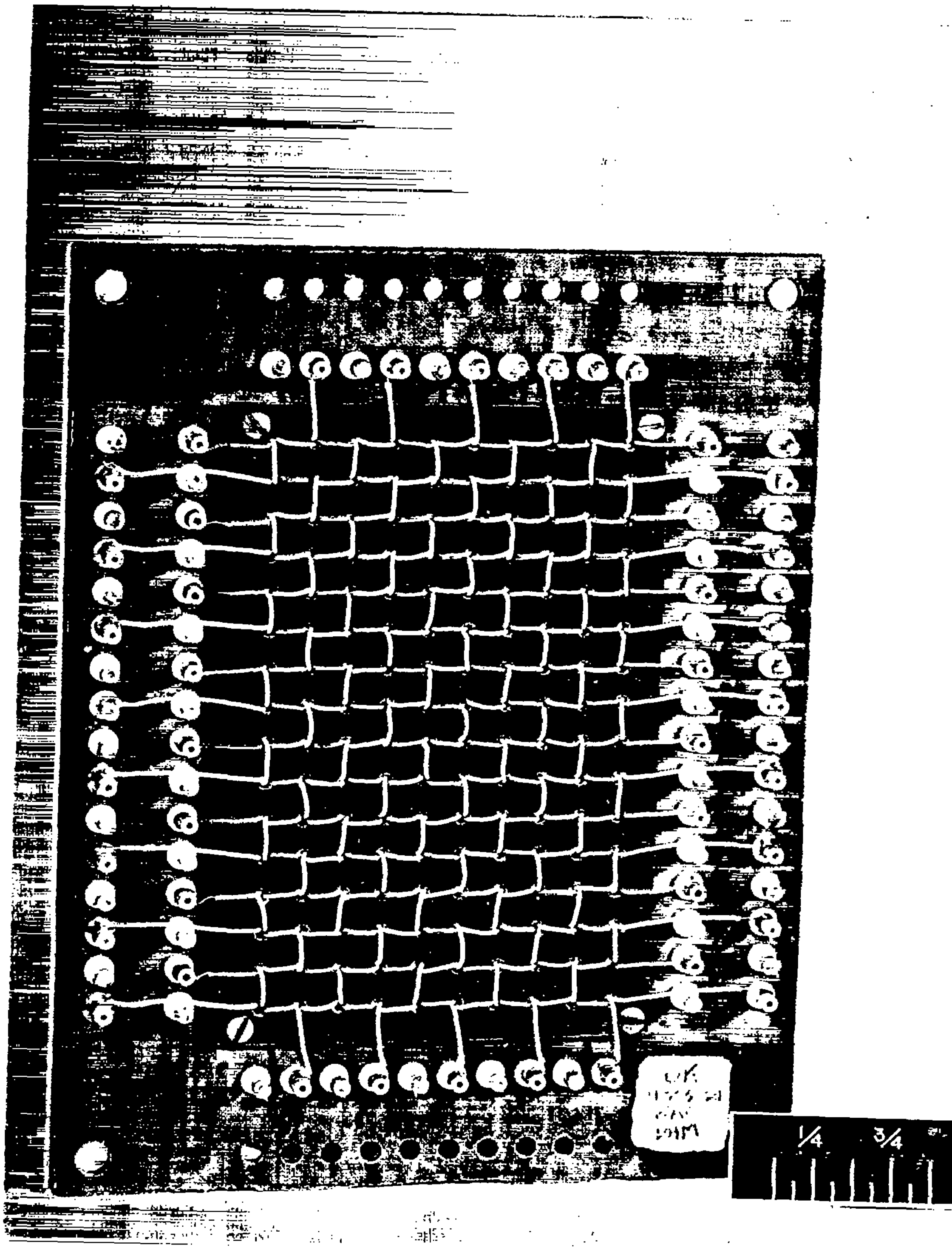

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Figure 10. - Ten-channel magnetic-core memory matrix.

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CHAPTER VI

PLAYBACK AND CONTROL ROOM EQUIPMENT

By John Ryskamp

Once the experimental data have been recorded on magnetic tape, the problem of inspecting and using the data still remains. For the CADDE operators an array of neon lights on the CADDE console permits visual inspection of the data as it is played back from the magnetic tape. Also available to the CADDE operators as well as to the test engineers in their control rooms are Flexowriters and facsimile plotters which type and plot the recorded data for examination and filing. For conversion of the raw data into final computed test results, an ERA 1103 high-speed digital scientific computer is available. Each of these means of playback involves the use of its own shift register. There are, therefore, four shift registers associated with the playback modes of operation. The function of each of these shift registers is to take each data word as it comes from the tape in serial form, hold each word temporarily until the associated equipment decides what to do with it, and then feed this word to the output device in a form it can handle.

The block diagram in figure 1 shows five tape handlers, A, B, C, D, and X, upon which the data can be recorded. As can be seen, all information to be recorded must pass through shift register A. Also shown are the four output devices, Flexowriters A and B, the facsimile plotter, and the computer. The interconnecting lines and arrows show the method of connecting the tape handlers to the various output devices and the direction in which the information flows. Corresponding to the four output buses from the four tape handlers on figure 1 are four vertical columns of pushbuttons on the CADDE control console; each column is associated with one of the four tape handlers. For each of the intersections on figure 1 of the output buses from the tape handlers with the playback buses to the playback devices, a corresponding pushbutton on the console controls that particular connection of a tape handler to a playback device. These pushbuttons are called "type", "plot", or "compute", according to the function they perform and will be referred to as such later in the report. Each of these playback modes will now be discussed in turn.

MODES ASSOCIATED WITH SHIFT REGISTER A

Manual Inspection

The recording function of shift register A in conjunction with tape handlers A, B, C, and D has already been discussed. Shift register A, however, can also be used on playback for manual visualization and examination of the recorded information. If the CADDE operator desires to inspect visually what has been recorded, switches on the CADDE console will allow him to select any tape handler manually. Once the tape handler has been selected, other controls permit the backward indexing of the tape either one word at a time or one reading at a time. In each case, the tape handler comes to an automatically controlled stop after the word or reading has passed through the shift register. The last word to pass into the shift register is displayed on a neon-light array on the CADDE control console. Manual forward indexing of the tape handler one word at a time is also provided which permits a complete and careful examination of each recorded data word.

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Automatic Inspection

When using shift register A it is possible to make a permanent typewritten copy of the data. As can be seen from figure 1, it is possible to connect tape handler A, B, C, or D through shift register A to Flexowriter A, and also, if desired, to any remote Flexowriter. When this mode of operation is desired, the proper tape handler is selected manually, indexed to the beginning of the desired reading, and then caused to type out every word of the reading automatically. This mode of operation is called the "type all" mode. Figure 2 shows the format of a typical typewritten copy.

Each group of eight digits in figure 2 is considered a word. The first two digits of each word comprise the word number. The second two digits comprise the coding field which controls the operation of the Flexowriter and performs other functions. The last four digits of each word describe the physical quantity being measured.

The first group of seven words is preliminary or general information which identifies the record which follows. The first word, 01, contains the program number which identifies the facility making the test. The number 3010 is a code number for one of the facilities. The second word, 02, contains the reading number. In this case the four dashes indicate that the record was a test run and not an actual data run. Word 03 contains the date, 0809, which was August 9. Word 04 contains the time based on a 24-hour clock, 1414 or 2:14 P.M. Words 05 and 06 contain the numbers 7777 and 8888, respectively, which are test numbers used to check the recording equipment. Word 07 contains the barometric pressure, which at the time of this recording was 29.23 inches of mercury.

The next two large groups of words each contain 100 pressure measurements. The word number identifies the source of the pressure, and the last four digits are the raw data representation of each pressure being measured. The close agreement in the data digits of each channel indicates that the same pressure was on all channels. The single word at the end of the record is the reading number which is always recorded. This word contains the same information as word number 02 at the beginning of the record plus a character indicating that this is the last word of the record.

The manner in which this typewritten copy is obtained can be explained with the aid of figure 3. The initial start command is given by the operator to the Flexowriter control circuit which from then on controls the entire typing sequence automatically. The control circuit sends a "start" command to the tape handler which then runs in the forward direction until one complete word has been transferred from the magnetic tape to the shift register. The tape handler then receives a "stop" command from the control circuit which halts the tape handler until the data word in the shift register has been completely typed. When the word is in the register, the first function that is performed is an automatic examination of the channel number and the editing and control fields to see what functions shall be performed. For example, an 01 in the channel number field will cause a double carriage return. This double carriage return feature is useful in separating data into groups of 100 channels and in separating data which have come from different sources. (This is due to the fact that the channel number is reset to 01 each time the data source is changed, for instance, among general information, voltages, and pressures.)

After the double carriage return command has been carried out, if present, the editing and control field is examined and its commands are carried out. The various codes which can be present in this field and the functions they cause to be performed by the Flexowriter are listed in the following table:

Editing and control field codes	Function to be performed
01	End of record, stop typing
10	Select type, type only words having this code
20	Begin typing every word until next "select type" code is reached
40	Single carriage return
80	Beginning of record, start typing

All these codes can be used in any combination with each other with the indicated functions being performed without interference with each other. If neither a single nor a double carriage return command is received during this examination period, a space command is automatically given to the Flexowriter to provide for spacing between words. It should be pointed out and emphasized that these codes are recorded with the data word on the recording cycle as determined by the wiring of the plugboard associated with the tape handler. This enables the format of the typewritten copy to be predetermined for a particular recording and places the Flexowriter entirely under the control of the recorded information on the magnetic tape.

Once these normal typewriter functions have been attended to, the typewriter is then free to type the eight characters of the data word. Since the Flexowriter is capable of printing only one character at a time, the control circuit looks only at the character which is in the 10's decade of the channel number field. The combination of the 4 bits in this decade will be interpreted by the Flexowriter as a number, and then the appropriate character will be typed. In the illustration shown in figure 3, the "1" and "2" bits of the 10's decade combine to print "3" as the first character of the word. When this character has been typed, the Flexowriter signals the control circuit that it is ready to type another character. The control circuit then shifts each character in the shift register to the left one decade. The character now in the 10's decade of the channel number field is the "8" which was in the 1's decade of that same field. When the shift is completed, the Flexowriter then types the character "8". This procedure is repeated eight times, once for each decade until all eight digits have been typed. When one word has been completely typed, the tape handler is started again, and a new word is read into the shift register. Thus, the process is repeated for each word until an entire reading has been typed.

A second mode of operation is available using the Flexowriter called the "select type" mode. In this mode of operation only certain predetermined words are typed. The words which are typed are those that have a "select type" code recorded with them in the editing and control field as determined by the plugboard on the recording cycle. This feature allows a faster type back since only the words of greatest interest are typed. The typing rate in all cases is approximately one word per second.

The remote Flexowriters are selected by means of the plugboard previously mentioned and are slave units of the CADDE typewriter, typing whatever information the CADDE typewriter has typed. Also, each of these playback modes is interlocked against interfering with the recording cycle in any way. If shift register A is being used for a recording, it is impossible to change modes to use shift register A for any type of playback from any other tape handler. Conversely, if shift register A is being used for playback, no recording can be made.

Punched Paper Tape to Magnetic Tape

Another mode of operation available to shift register A is a provision to permit the preparation of magnetic tapes from punched paper tapes. When this mode of operation is used, a punched paper tape is first prepared on a Flexowriter. The punched paper tape is then inserted in the reader of Flexowriter A, and the coded paper-tape information is read into shift register A. The shift register assembles the information coming from the reader, and, after it has received a complete word, it shifts this information out serially, 1 bit at a time, onto the magnetic tape. After one word has been recorded, the shift register is ready for the next word; the cycle is repeated for each word. This mode of operation is used to prepare certain test tapes for the computer.

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Tape Handler X

Figure 4 shows that shift register A is also used for recording information on tape handler X. Tape handler X differs from the other four tape handlers both in purpose and construction. Its purpose is to monitor what is being recorded on the other four tape handlers and to provide an automatic playback of the monitored information. The playback is made through a second shift register called shift register B. This shift register sends the information to a monitor Flexowriter called Flexowriter B. It performs this function by using one head for recording on a continuous loop of tape and a second head for playback. As can be seen from figure 4, the continuous loop is stored in two bins. Bin A holds that tape containing recorded information not yet played back, while bin B contains the tape which has been played back and is now avilable for recording again. A switch in bin A, which is actuated when the tape between the recording and playback heads is taut, indicates when all the recorded information has been played back, since a sufficient amount of tape is always metered out after recording.

When information is recorded on any of the other four tape handlers, all the words which have a "select type" (10) code recorded on them as determined by the plugboard are recorded also on tape handler X. In this case the 10 code has the significance of "select and record". As soon as the recording has been completed, the tape containing the select-recorded information on tape handler X is made to pass by the playback head. This information is then assembled in shift register B and is sent to Flexowriter B. A remote type back of this information can be made with the remote Flexowriters in this case slaving on Flexowriter B.

In this mode of operation the selection of the proper remote Flexowriter must be accomplished automatically since tape handler X can contain the intermixed readings of four different facilities in any order. This automatic selection is accomplished by examining the first word of the reading, since it contains the program number identifying the facility which made the reading.

These automatic type backs of all the select-recorded words provide a continuously kept log of recorded information and relieve the CADDE operators of a great deal of work normally associated with the manual monitoring of recorded data. 4256

MODES ASSOCIATED WITH SHIFT REGISTER B

Full Type Back Mode

The need arises at times for a full type back of a complete reading to be made directly from any of the four main tape handlers. Although shift register A is capable of doing this, there are many times when it must remain free for use in the recording cycle. Shift register B, therefore, is used not only for type backs to Flexowriter B from tape handler X, but also for type backs to Flexowriter A from tape handlers A, B, C, and D. The selection of the proper tape handler is accomplished by depressing the appropriate "type" pushbutton on the console, after which the operation is completely automatic.

The sequence of events after a tape handler is selected is as follows: The tape handler runs in reverse until it finds the first word at which time it automatically stops. The Flexowriter is then turned on automatically and from then on proceeds in identically the same manner as discussed in the section entitled MODES ASSOCIATED WITH SHIFT REGISTER A.

Since shift register B is used for type backs either to Flexowriter B from tape handler X or to Flexowriter A from tape handlers A, B, C, or D, interlocks exist to prevent shift register B from being used for both purposes simultaneously. The normal mode of operations for shift register B is to make select type backs from tape handler X to Flexowriter B.

Select Type Back Mode

Select type backs can also be made with shift register B on Flexowriter A in identically the same manner as for shift register A. This is controlled by means of other pushbuttons called "select type" on the control console associated with each type handler.

Consecutive Type Back Mode

Sometimes it is necessary to type out a number of consecutive readings from one of the four main tape handlers. It is then desirable to override the reversing feature of the automatic sequence of events normally associated with "type" pushbuttons. This can be accomplished by pushing the "reverse inhibit" buttons on the console associated with each of the four tape handlers. When the "reverse inhibit" button is pushed, the tape handler selected by means of the "type" buttons will not reverse but instead will first turn on the Flexowriter and then type information coming from the tape handler which will now only run in the forward direction. Now, as long as the "reverse inhibit" is engaged, the next reading on the tape will be typed each time the "type" button is depressed. Either a "full type" or "select type" can be made in the "reverse inhibit" mode. In each of these modes remote type backs can be made with the selection of the remote Flexowriters made automatically as discussed in the section entitled Tape Handler X.

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FACSIMILE PLOTTER

Another means of playback for the CADDE operators and tunnel test engineers provides them a much easier and more rapid method of surveying their recorded raw data. This is accomplished by means of a facsimile plotter. As can be seen from the main block diagram of the playback system (fig. 1), each of the four tape handlers can be connected to the plotter located at CADDE. Also, located in each of the control rooms of the facilities connected to CADDE is a plotter which can also be connected to any of the four tape handlers. Upon a single command given by a CADDE operator, which consists of merely depressing the "plot" control pushbutton, a tape handler can be selected and caused to have its data plotted. The plotting cycle, which is entirely automatic, consists of the following sequence of events: The chosen tape handler is connected to the facsimile shift register, and the tape handler is automatically indexed backwards until it finds the first word of the reading, at which time it stops. The plotter is turned on automatically, and, when it has reached its proper running speed, the tape handler feeds one word at a time to it for plotting. The tape handler is started and stopped once for each data word plotted. Plotting is accomplished at a rate of 15 words per second. As in other playback modes, the playback cycle is completed and stopped when a word containing an 01, or "end of record," code is reached.

The basic plot which is made has for its abscissa the channel number and for its ordinate a full-scale reading of 10,000 counts or divisions. Thus, any four-digit number can be plotted on this graph, whether it be pressures, voltages, frequency data, or general information. The type of presentation made by this plotter is similar to a manometer board display and is an operational aid to the test engineer. It provides the means for a rapid visual survey of the data and also gives a quick check of the instrumentation.

The plotter used in making this type of plot has for its plotting medium a moist, electrochemical paper which is fed between two electrodes as shown in figure 5. One of these electrodes is stationary. The other consists of a one-turn helical wire mounted on a drum which is motor-driven. When the drum rotates, the helical wire electrode continually scans the width of the paper. Since the paper feed direction is at right angles to the scan, each succeeding scan starts at an incremental distance farther along the top of the paper. If at any time during a scan a suitable voltage is applied between the recording electrodes, a line is drawn for the length of time the voltage is maintained. The scanning rate of the drum is 30 scans per second. The paper feed rate is such as to produce 50 lines per inch. The instrument used by NACA for this application is a modified version of a commercially available item.

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The heart of the operation centers around the combined shift register-counter. This shift register-counter is identical to the other shift registers discussed except for one important difference. It has had the necessary circuitry added to enable it upon command to also function as an ordinary binary decimal counter. In its cycle of operation the shift register-counter first performs as a shift register, during which time one word from the magnetic tape is read into the register. The shift register-counter is then connected to perform as a counter, during which time pulses are fed to the count input. Each pulse fed to the count input causes the stored number to increase by one. If enough pulses are added, the counter reaches its capacity count, which is 9999 for the four decades. Addition of one more pulse causes an overflow or carry pulse to be emitted by the 1000's decade. The number of pulses which must be added to the originally stored number to produce a carry pulse is the 10,000's complement of that number. By this process a time interval has been created which is proportional to the 10,000's complement of the number.

Figure 6 shows how the shift register-counter functions in conjunction with the plotter. A synchronizing pulse is derived from the plotter at the beginning of each scan. The first pulse signals the tape handler to read one number into the shift register-counter. During the time the word is being read into the register, the plotter completes its scan. No data write signals occur during this period.

At the beginning of the next scan, the synchronizing pulse from the plotter starts the oscillator, which feeds pulses to the count input of the shift register-counter. At the point in the scan where the carry occurs, the carry pulse is used to mark the plotting paper. The action forms a plot in the following manner: Figure 7 represents the plotting paper, and all scans start at the top of the paper. Also, the oscillator frequency is adjusted so that 10,000 pulses occur in a time interval equal to that required for a full scan of the paper. As a plotting scan begins, the oscillator starts to drive the shift register-counter toward a carry. At the point of carry the plotter is signaled to start drawing a line of arbitrary length along its scan. Since the full width of the page represents 10,000 pulses, the distance from the top of the page to the beginning of the mark represents 10,000 minus the number read from the tape. The remainder of the distance down the page, then, is the number on the tape. The top edge of the mark is the required point plot of the number. High numbers would be plotted nearer the top; smaller numbers nearer the bottom.

The alternate reading of tape and plotting continues at a speed determined by the scanning rate of the plotter. This rate is 30 scans per second. Since plotting is done on only every other scan, the numbers from the tape are read and plotted at a rate of 15 per second. Figure 8 shows a typical facsimile data plot.

To make this plot more readable and usable a number of features have been added as shown in figure 9. The most important of these additions are the calibration grids. Now the paper is divided into ten major divisions each of which is divided into ten minor divisions. Calibration takes place on alternate scans when a new word is being read from tape. No data plotting is done during these scans.

To accomplish the calibration, the oscillator which drives the shift register-counter on the data plotting scan is now used to drive the calibration counter on the nondata plotting scans. (This calibration counter is also used on the data plotting scans to meter out the required number of pulses to produce a carry pulse from the shift register-counter regardless of what the number is in the shift register-counter.) During this calibration scan, at each 1/100 full-scale incremental advance of the calibration counter, a minor calibration mark is derived from an appropriate tap-off point of the counter which is then used to mark the paper. A major calibration mark is made for each 1/10 full-scale incremental advance of the calibration counter. On each nondata scan, then, 100 such calibration marks are drawn. The effect of making these marks on alternate scans is to give the appearance of a series of horizontal lines along the width of the plot. Major calibration marks are differentiated from minor calibration marks by using two different length marks.

A second feature which has been added to the plot in figure 9 is the insertion of a blank space at the beginning of a group of logically related data. This is controlled by recording a "space" code on the first word of each group of logically related data. The facsimile electronic equipment will then sense this code and insert the space.

The diagonal patterns of marks are plots of the channel number. This number is also read from the magnetic tape where the channel number is recorded with each data number. Plotting of channel number is handled in a fashion similar to the plotting of data. In this case, however, since the highest channel number is 100, only 100 pulses are required to count out, to a point of carry, that portion of the shift register-counter in which the channel number is stored as shown in figure 6. These pulses are obtained from a tap-off point in the metering counter where the input frequency to this counter has been divided down sufficiently. By this means the channel number pulses and the data number pulses occur at the same time and are in perfect phase relation. Therefore, the calibration lines drawn for the data can also be used for reading the channel number by considering full scale in the latter case to be 100 rather than 10,000. The counting of the data and the channel number is done simultaneously, and the plots appear on the same scan.

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A third feature which has been added is one which permits a change of resolution of the plot from so-called "normal" to "dual" resolution. When this resolution is used, the "count input" terminals and "carry out" terminals of the shift register-counter are changed as well as the number of pulses which are fed into the "count input" terminals. Figure 10(a) shows the connections used for the normal resolution case, in which the 10,000 pulses are fed into the 1's decade and the carry pulse is taken out of the 1000's decade of the data field. Figure 10(b) shows the connections used for the double resolution case in which there are now two count input terminals, one in the 1's decade and one in the 100's decade. In this case only 100 pulses are fed into each count input terminal, and a carry pulse is looked for at the output of the 10's and the 1000's decades. Only 100 pulses are needed in each case since only two decades are being driven. The carry pulses from the 10's and the 1000's decades are caused to plot lines of different lengths, with the output of the 1000's decade being longer to indicate its greater value. Both carrys are plotted on the same scan along with the channel number. This feature enables the entire four-digit data number to be read with complete accuracy since it, in effect, breaks the number up into two completely readable points which, when added together, give the data number. This feature is used extensively in checking the accuracy of the capsules on the DAMPR scanning tanks. Figure 11(a) shows a plot of a typical capsule check. The longer marks are all in a line since they represent the higher ordered digits, whereas the shorter marks vary in position since they show up the minor variations from capsule to capsule. Figure 11(b) shows the same reading plotted using normal resolution.

COMPUTER OUTPUT

The playback devices which have been discussed are only monitoring devices used for the examination of the raw data. This examination is desirable from the standpoint of the operators to check on the correct operation of the recording equipment, which is quite complex. It is also desirable from the standpoint of the test engineer, since it permits a rapid check of the instrumentation of a test setup, which is also quite complex. It also is capable of showing trends during a test, which gives the project engineers an idea of how the test is progressing.

The main purpose of CADDE, however, is to record the data on magnetic tape in a form that can be read directly into the large-scale scientific digital computer. Figure 1 shows that any of the four main tape handlers can be connected to the computer. This is accomplished by the CADDE operator depressing the appropriate "compute" button on the CADDE control console. When this button is depressed it connects the necessary control and signal lines to the computer, which then has complete control over the tape handler. The computer can start, stop, and reserve the tape handler according to a predetermined program stored in the memory of the computer. This computer will perform the computations on the raw data as called for by the program, and, when the computations have been completed, the computer will return control of the tape handler to CADDE.

REMARKS

As has been pointed out, each of these means of playback is independent of the other, since each has its own control circuits and shift register. Appropriate interlocks exist which will allow all four tape handlers to be busy at the same time performing some playback function or recording without interference with each other. Interlocks also exist, of course, to prevent any playback device from being connected to a given tape handler while the tape handler is either recording or engaged with another playback device.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, November 22, 1957

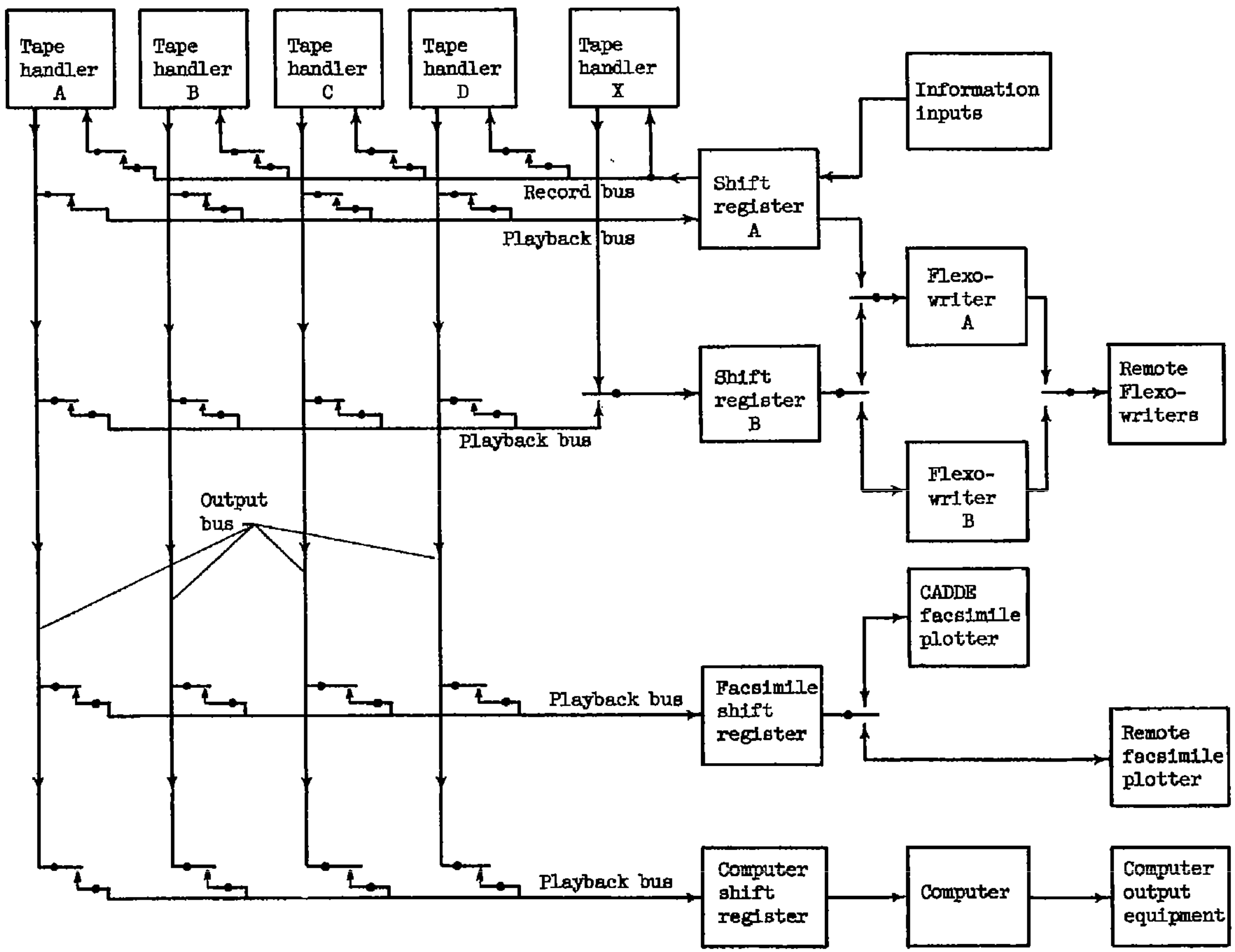

Figure 1. - Block diagram of CADDE playback equipment.

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01,03010 0200---- 03000809 04001414 05007777 06008888 07102923

01600623 02100623 03000624 04000623 05000623 06009331 07209330 08009330
11008974 12008972 13008973 14008973 15008974 16000716 17000715 18000715
21408832 22008833 23008832 24008833 25008832 26108505 27008502 28008503
31108973 32008972 33008974 34008974 35008975 36008975 37008972 38008974
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71008975 72008973 73008975 74008973 75008504 76008503 77008507 78008503
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91008503 92008505 93008506 94008505 95008505 96008503 97008504 98008504

0111----
```

Figure 2. - Typical typewritten copy.

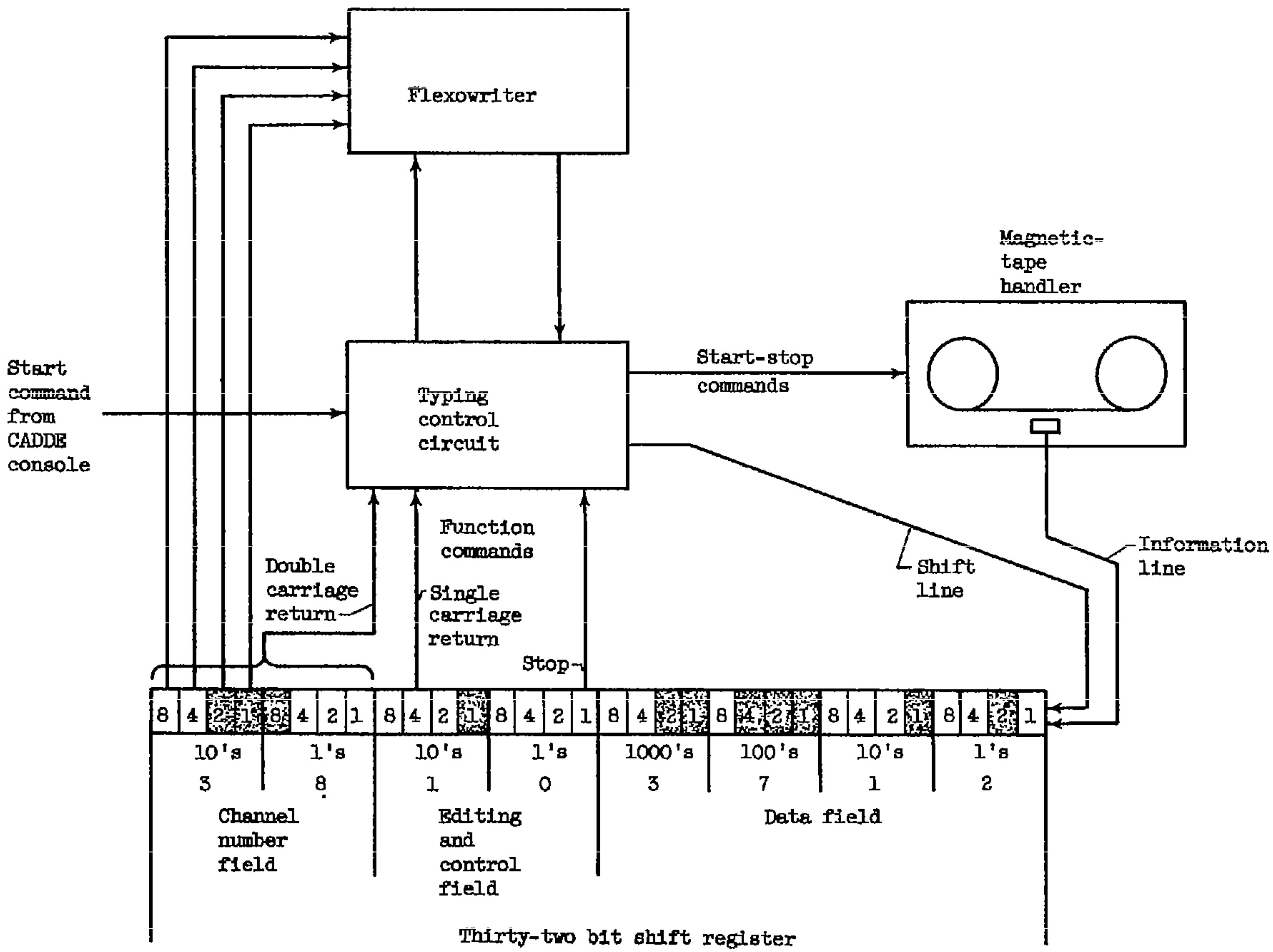


Figure 3. - Block diagram of Flexowriter logic.

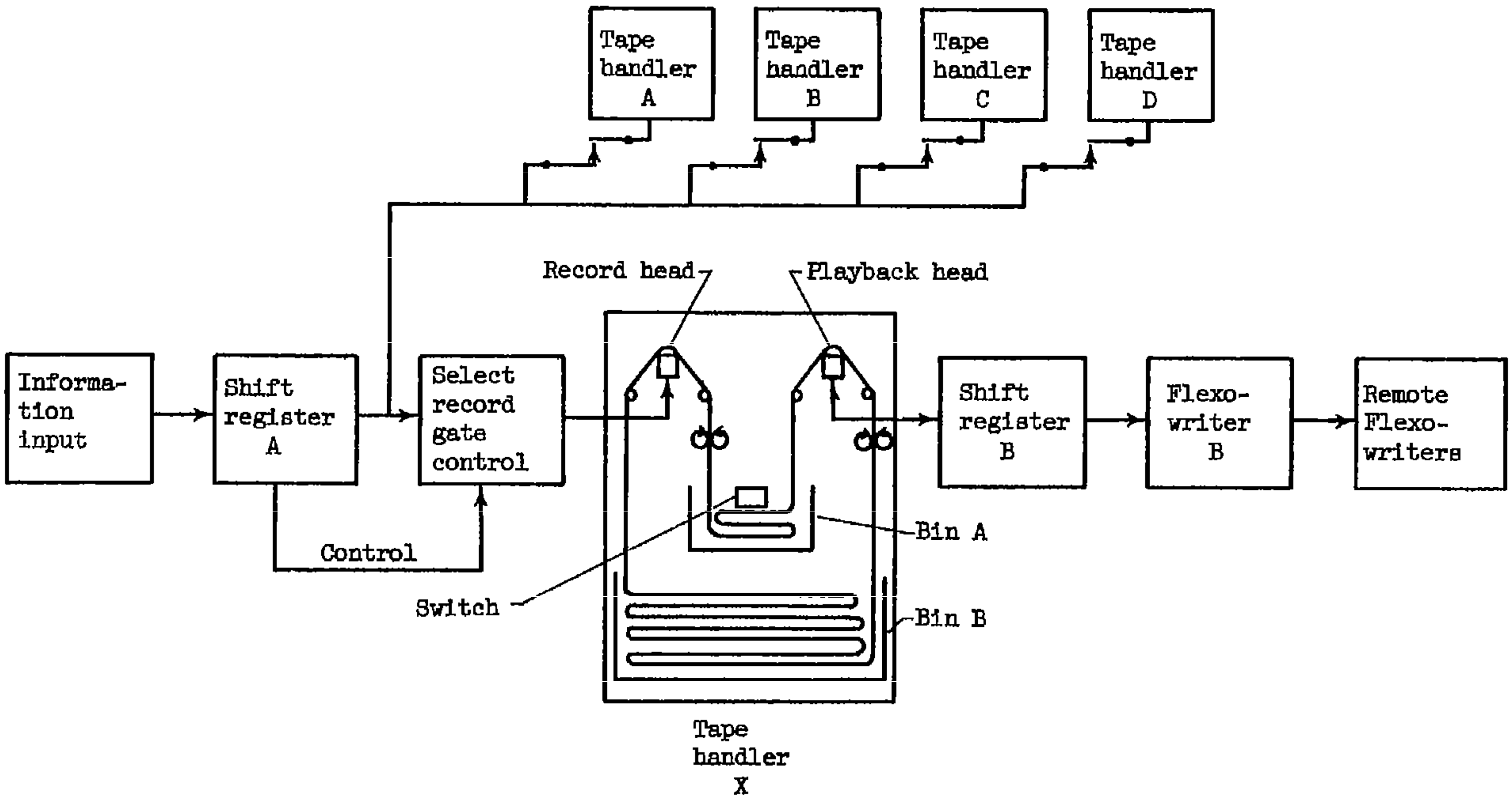


Figure 4. - Tape handler X operation

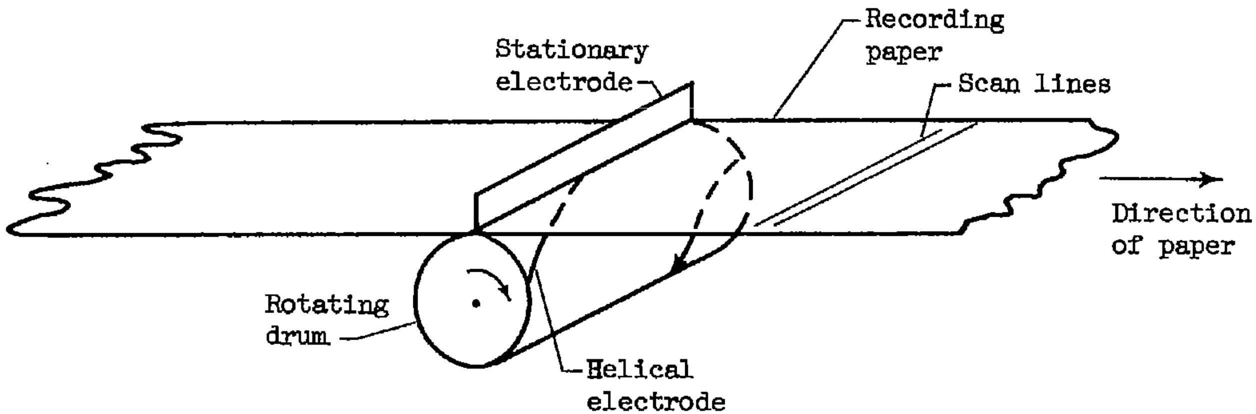


Figure 5. - Basic plotter recording mechanism.

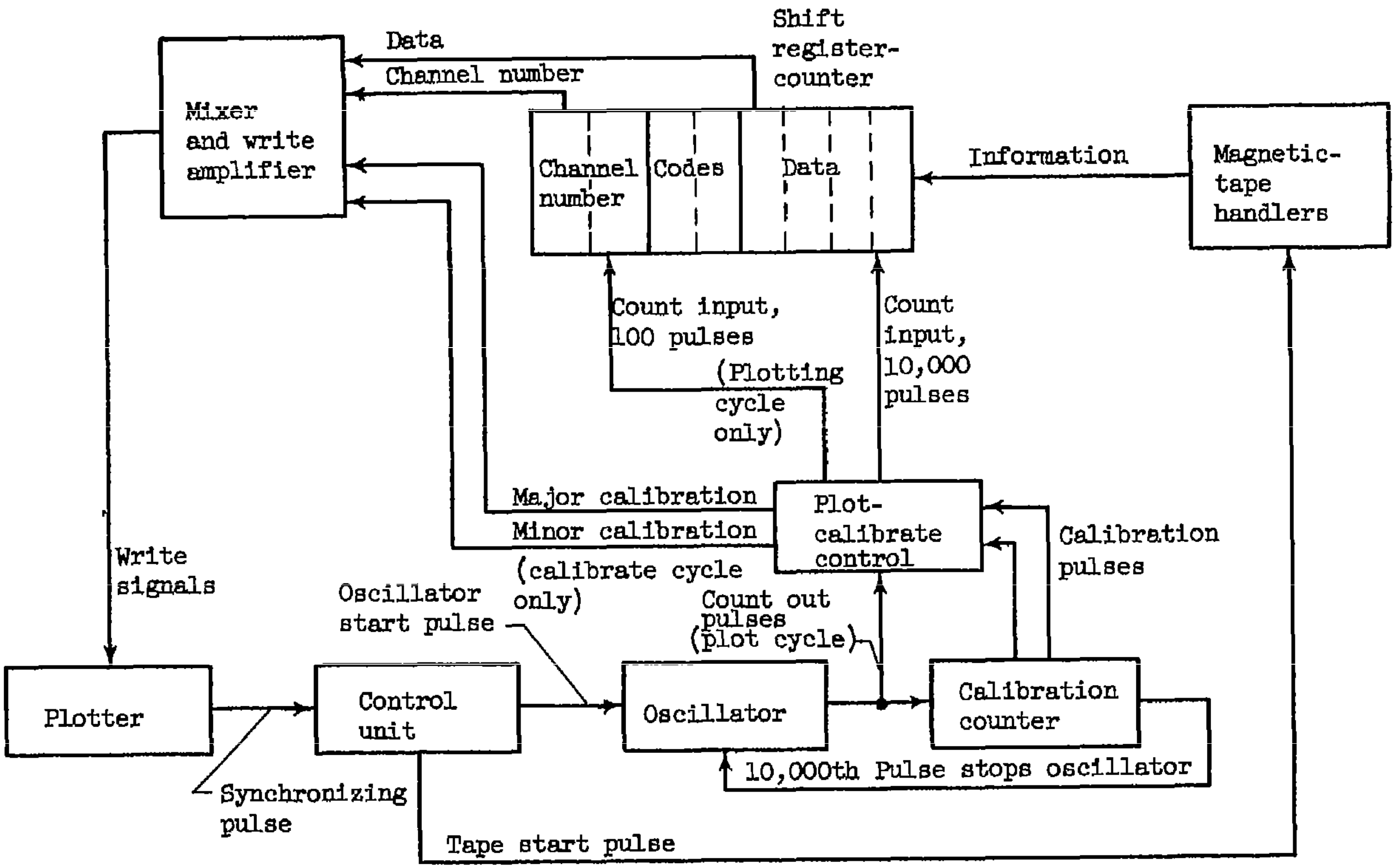


Figure 6. - Block diagram of facsimile plotter.

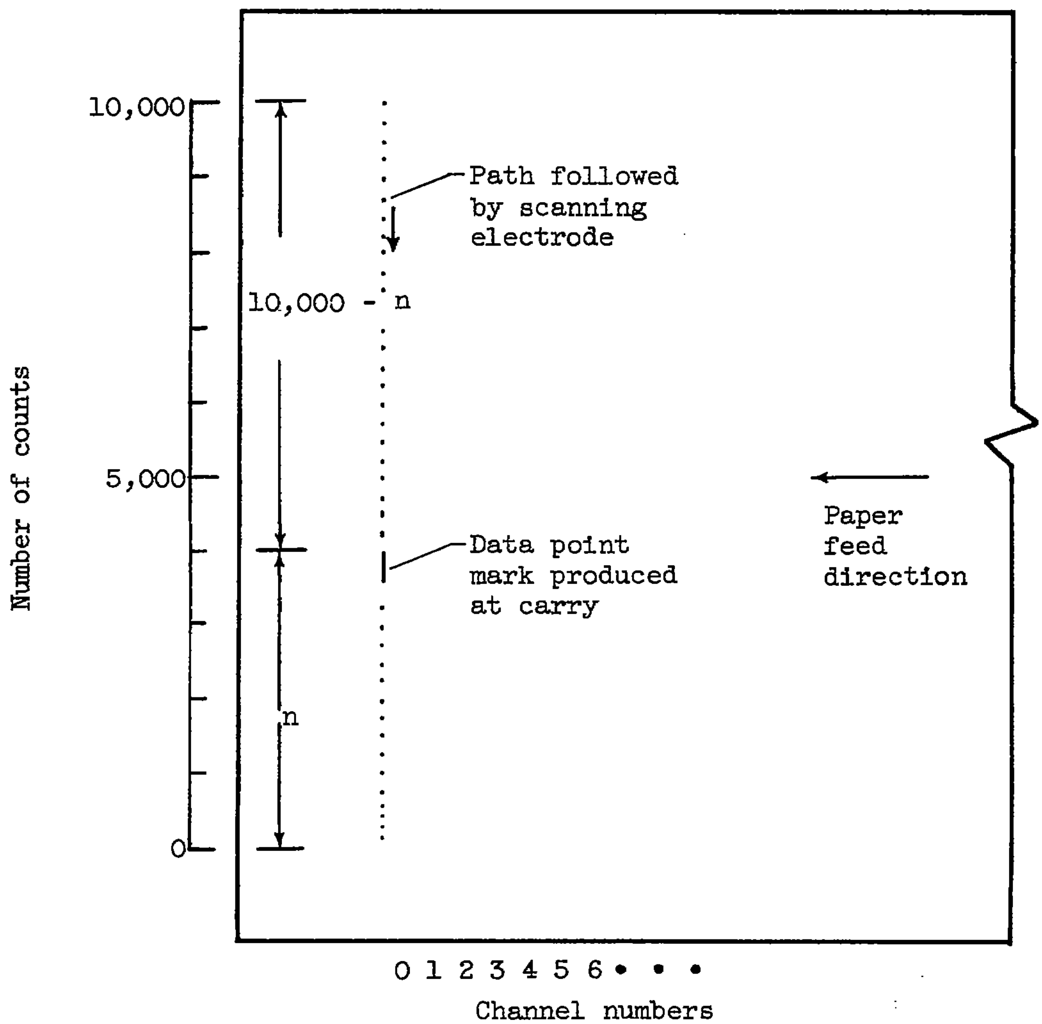


Figure 7. - Method used by facsimile plotter to mark paper.

Figure 8. - Typical facsimile data plot.

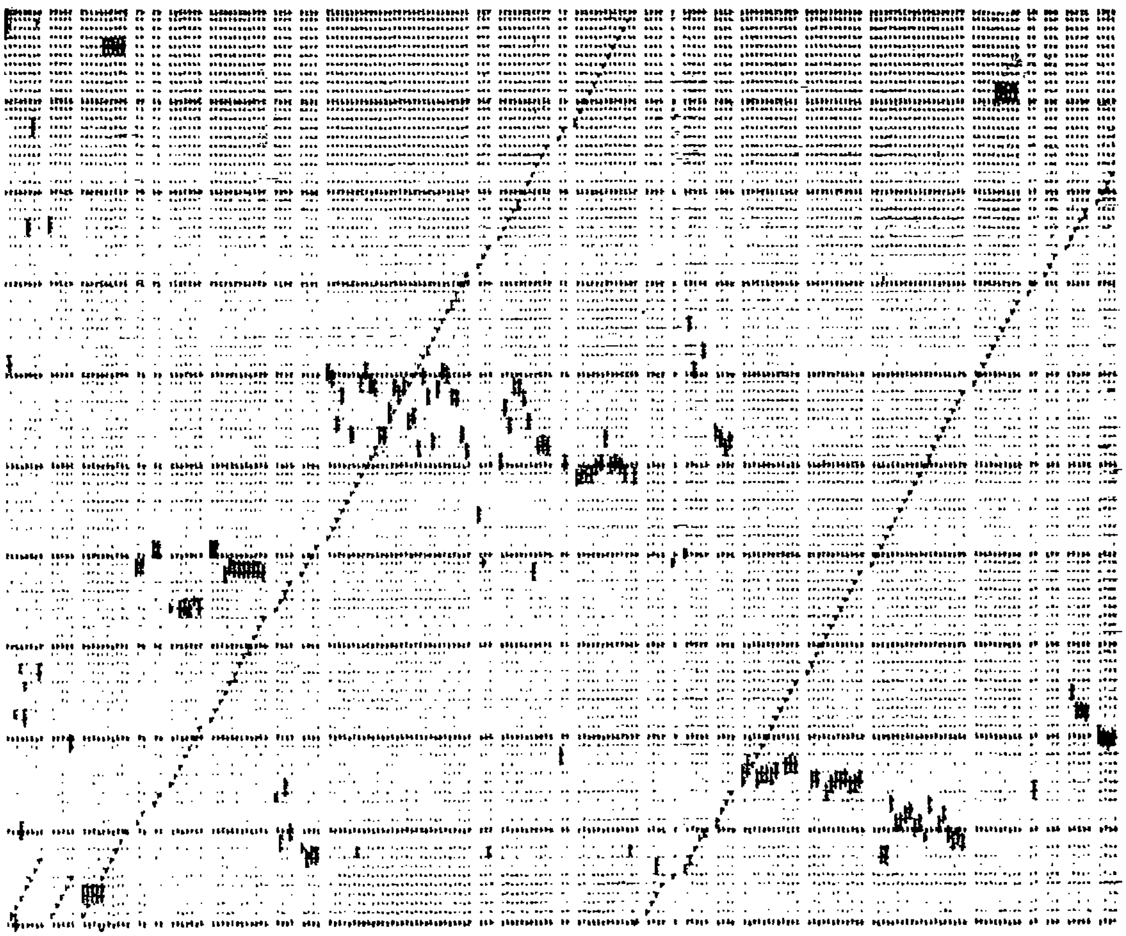
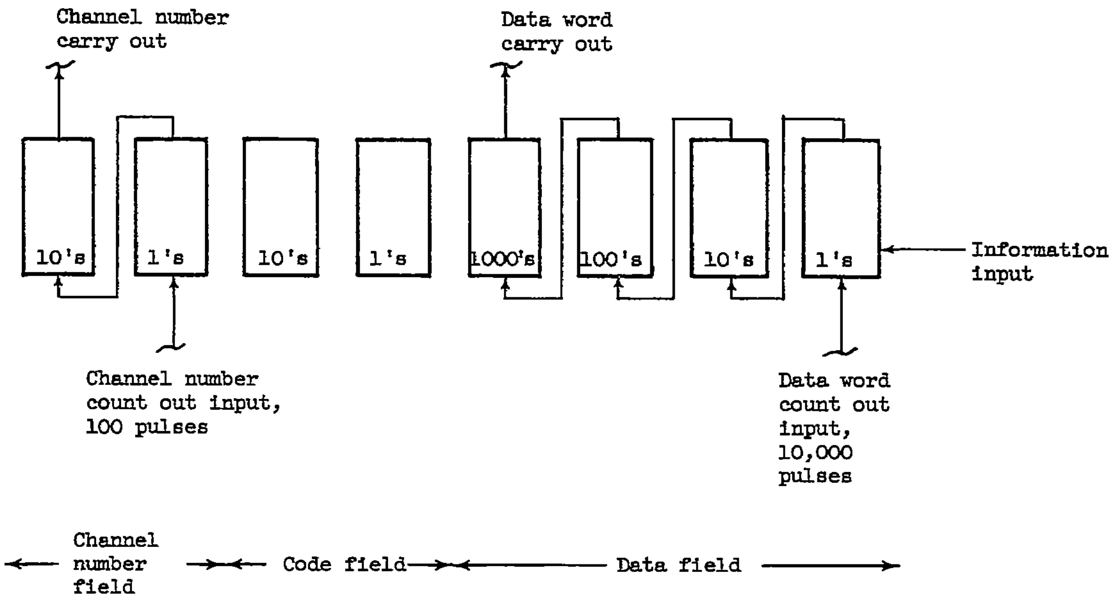
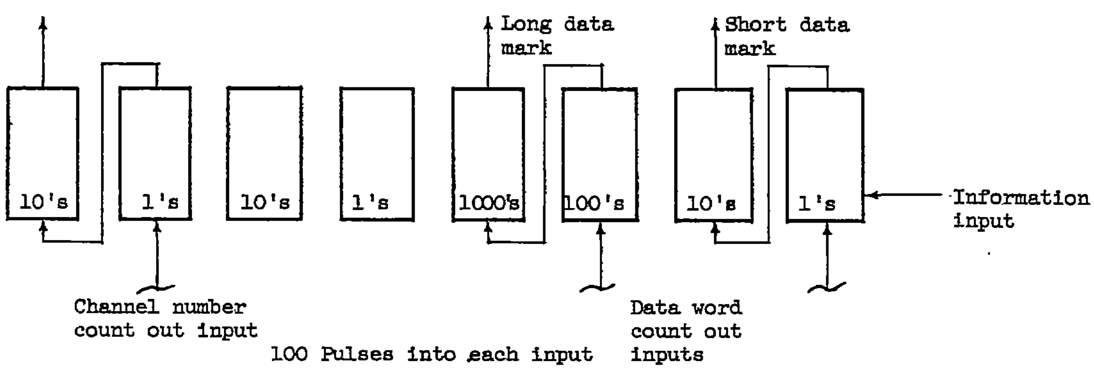


Figure 9. - Typical facsimile data plot with aid features added.

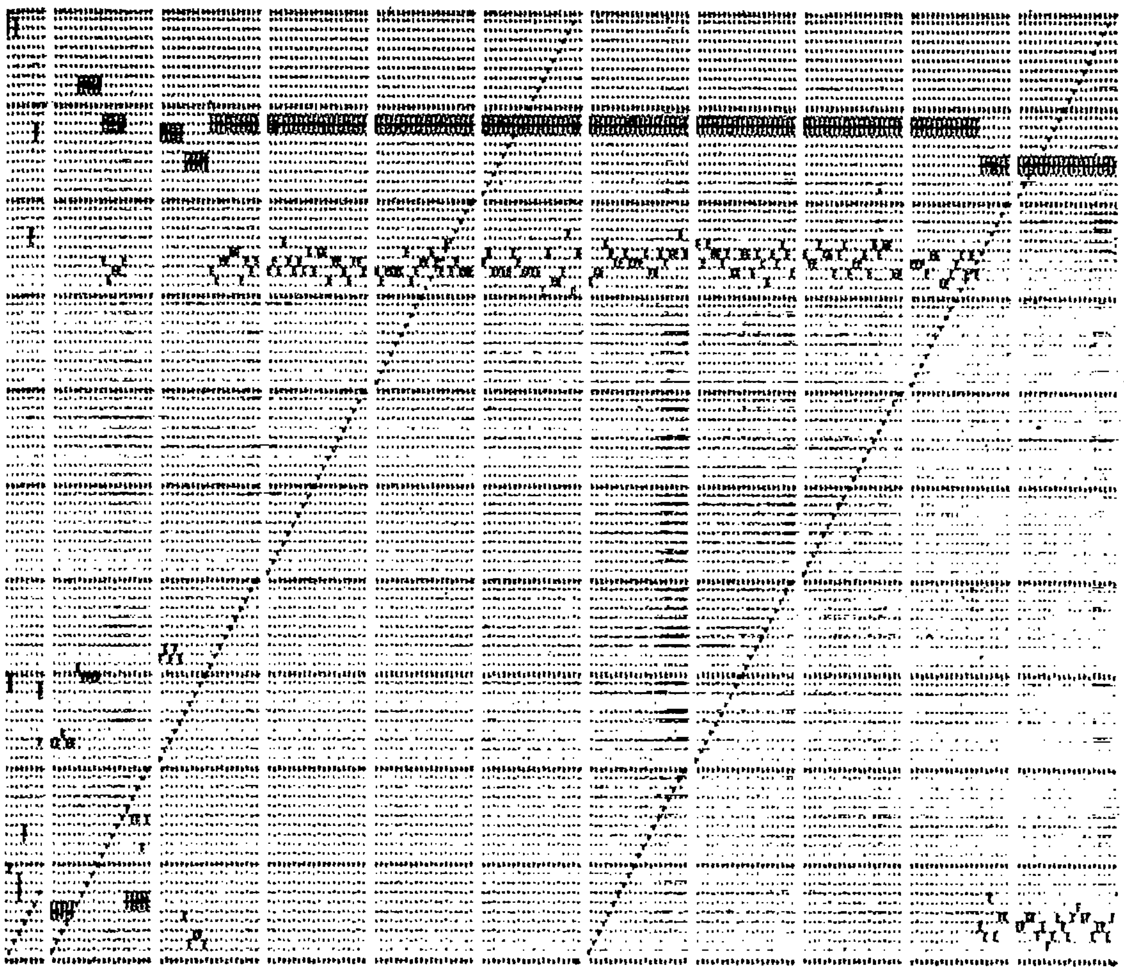


(a) Normal resolution.



(b) Dual resolution.

Figure 10. - Facsimile shift-register connection for different resolutions.



(a) Using dual resolution.

Figure 11. - Typical facsimile plot of a capsule check.

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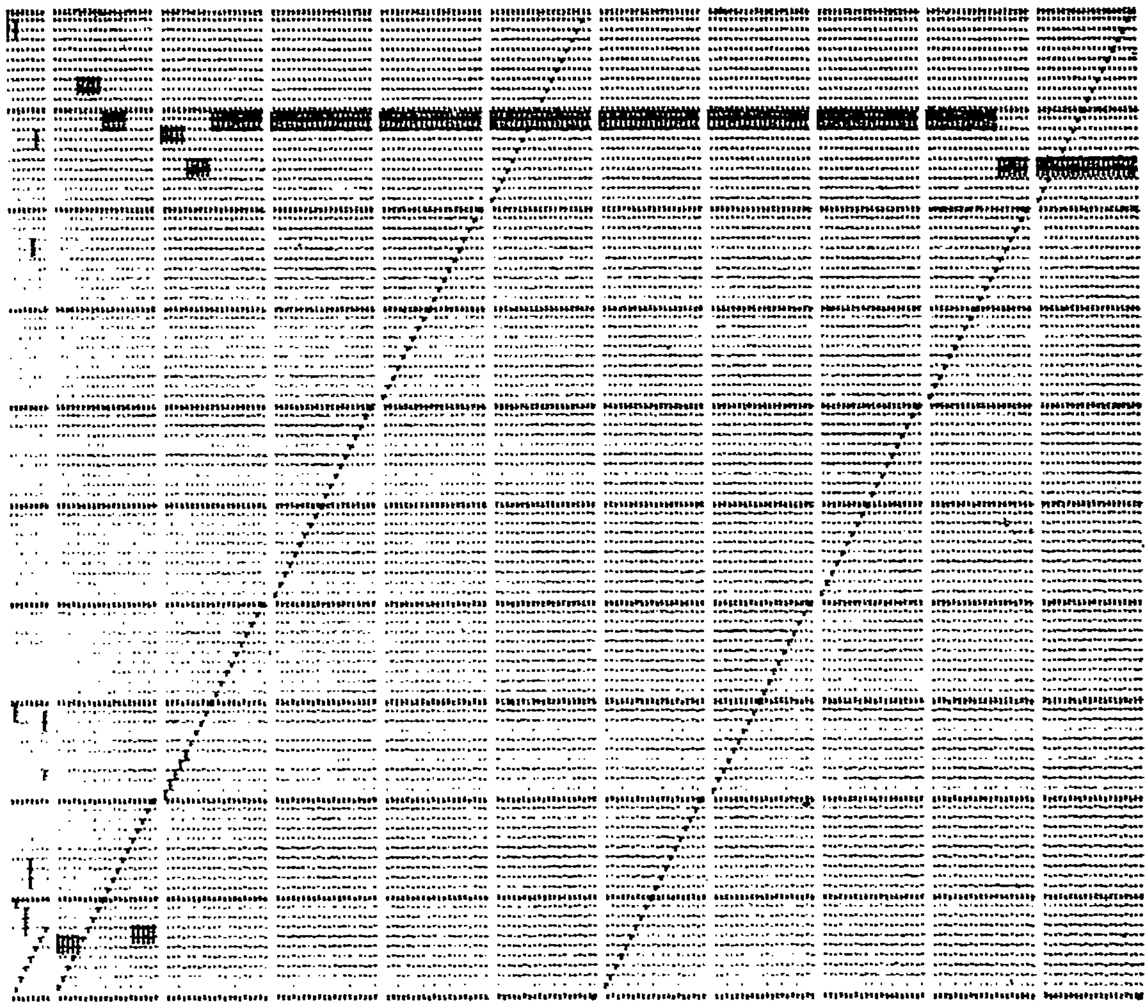

(b) Using normal resolution.

Figure 11. - Concluded. Typical facsimile plot of a capsule check.

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REFERENCE

1. Coss, Bert A., Daykin, D. R., Jaffe, Leonard, and Sharp, Elmer M.: A Digital Automatic Multiple Pressure Recorder. NACA TN 2880, 1953.